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Stratigraphical framework for the Ordovician and Silurian sedimentary strata of northern England and the Isle of Man

Geology and Landscape, England

Research Report RR/12/04

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE, ENGLAND

RESEARCH REPORT RR/12/04

Stratigraphical framework for the Ordovician and Silurian sedimentary strata of northern England and the Isle of Man

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Keywords

Report; stratigraphy, biostratigraphy, Ordovician, Silurian.

Front cover

Kirkley Bank Formation (Dent Group) at Moor Head, Troutbeck, Cumbria. Calcareous mudstone and siltstone with interbedded, brown-weathered, nodular limestone.

Bibliographical reference

MILLWARD, D, AND STONE, P . 2012. Stratigraphical framework for the Ordovician and Silurian sedimentary strata of northern England and the Isle of Man. *British Geological Survey Research Report*, RR/12/04. 119pp.

ISBN 978 0 85272 712 6

Keyworth, Nottingham British Geological Survey 2012

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Foreword

A stratigraphical framework for the Ordovician and Silurian sedimentary successions of the Lake District and adjacent areas of northern England, and the Isle of Man is presented herein. It arises from the modern 1:10 000-scale geological mapping undertaken by the British Geological Survey and its university partners, since 1981, during the Lake District Regional Geological Survey. The framework is a contribution to a more extensive review, undertaken by the Stratigraphy Committee of the British Geological Survey (BGS), of stratigraphical classification for all parts of the United Kingdom. Stratigraphical Framework Committees (SFC) were established to review problematical issues for various parts of the stratigraphical column. Each SFC has the following terms of reference:

- To review the lithostratigraphical nomenclature of designated stratigraphical intervals for a given region, identifying problems in classification and correlation.
- To propose a lithostratigraphical framework down to formation level.
- To organise peer review of the scheme.
- To present the results in a document suitable for publication.
- To ensure that full definitions of the lithostratigraphical units are held in the web-accessible *BGS Lexicon of named rock units* for the areas of responsibility covered by the SFC.

Acknowledgements

Many BGS staff and academic colleagues have contributed to the current well-established lithostratigraphical framework through their research in the Lake District. This assistance has been received at all stages of the study. In addition to the collection of data, many individuals have freely given their advice, and provided invaluable local knowledge. The final version of this report benefited from feedback provided by members of the BGS Stratigraphy Committee, and from the thorough and helpful reviews by A W A Rushton and M Williams on behalf of the Stratigraphy Commission of the Geological Society of London.

As this report was being completed, the authors were saddened to hear of the deaths of two stalwarts of Lake District research: Frank Moseley and Barrie Rickards. Their contributions over many years have been fundamental to our understanding of the Lower Palaeozoic development of northern England, and accordingly this report is dedicated to their memories.

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This report provides a comprehensive review of the lithostratigraphy of the Ordovician and Silurian sedimentary, excluding volcaniclastic, strata within the Lake District Lower Palaeozoic Inlier, the nearby northern England inliers of Cross Fell, Cautley and Dent, Craven and Teesdale, and the Isle of Man. It gives summary definitions of all the existing lithostratigraphical units, and attempts to resolve some of the inevitable anomalies resulting from the more than 20 years of recent research by members of the Lake District Regional Geological Survey team and academic collaborators. That research has led to publication of a new set of British Geological Survey (BGS) maps. This report complements the previously published review of the volcanic strata and intrusive igneous rocks of the same region (Millward, 2004, BGS Research Report RR/01/07).

The Ordovician sedimentary rocks of Cumbria comprise the Skiddaw Group, whereas those of the Isle of Man form the Manx Group. These groups are correlatives and the stratigraphy is essentially that previously published by the BGS, but with definitions expanded where required. The main change is that the Tailbert Formation is now re-assigned to the Borrowdale Volcanic Group, in recognition of its dominantly volcaniclastic composition and its unconformable relationships with the underlying rocks of the Skiddaw Group; in this respect it resembles the Latterbarrow Sandstone Formation seen at the base of the Borrowdale Volcanic Group in the west of its outcrop. As its definition was omitted from Millward (2004), the Tailbert Sandstone Formation is included in Appendix 4.

The Ingleton Group is considered here because of its long history of correlation with Lower Palaeozoic rocks in the Lake District. However, the absence of biostratigraphically significant fossils means that the group may equally be considered to be Precambrian in age. Though this conundrum remains unsolved, the petrological, structural and metamorphic characteristics of the Ingleton Group suggest that, on balance, these rocks should be regarded as Neoproterozoic in age.

The uppermost Ordovician and Silurian rocks of the region are included within the Windermere Supergroup, wholly divided into groups that reflect the dominant packages of lithofacies present: in ascending order they are the Dent Group, of Ordovician age, succeeded by the Silurian Stockdale, Tranearth, Coniston and Kendal groups. The definition of the Windermere Supergroup is now widened to include the Silurian (Wenlock) Dalby Group in the Isle of Man to emphasise likely correlation.

Only minor revisions have been made to the established constituent formations and their members, though definitions of many of these entries in the *BGS Lexicon of named rock units* are to be amplified from diverse literature sources. The most significant changes are summarised as follows:

- Within the Dent Group, the Low Scales Sandstone Member, formerly at the base of the Kirkley Bank Limestone Formation in the Furness district, is transferred to the Stile End Formation, remaining at the same rank. In the same area, the Ireleth Member of the Kirkley Bank Limestone Formation is replaced by the Kentmere Limestone Member of the same formation.
- In the Cross Fell Inlier, the term Swindale Shales is replaced by the Lake District Ash Gill Mudstone Formation.
- In the Craven inliers, it is recommended that the Llandovery rocks are assigned to the historic Stockdale Group and its constituent Skelgill and Browgill mudstone formations, rendering the relatively recently named Crummack Formation and its component Hunterstye and Capple Bank members obsolete.

- In the Craven inliers, it is further recommended that the term Arcow Formation is replaced by Coldwell Siltstone Formation which is in use across the rest of the region.
- Also in the Craven inliers, the Austwick Formation (Tranearth Group) is redefined to comprise only the sandstone-dominated succession, with its original lower part assigned to the Brathay Mudstone Formation. It is also recommended that the Horton Formation reverts to its earlier definition; consequently, its parent is the Tranearth Group. The Studfold Sandstone is elevated to formation rank within the Coniston Group. The siltstone succession (also previously part of the Horton Formation), overlying the Studfold Sandstone Formation and underlying the Neals Ing Sandstone Formation, is newly defined as the Sannat Hall Siltstone Formation.
- Within the Kendal Group of the southern Lake District, the Underbarrow Flag and Scout Hill formations become redundant and the strata subsumed within the Kirkby Moor Sandstone Formation.

1 Introduction

This stratigraphical framework report provides an overview of the Ordovician and Silurian sedimentary strata within the Lake District Lower Palaeozoic Inlier and their correlative units in the nearby northern England inliers of Cross Fell, Cautley, Dent, Craven and Teesdale (Figure 1). The Ordovician and Silurian rocks of the Isle of Man are also considered because of their long-held correlation with those in the Lake District. Also included, for reasons of similar historical correlation are the Ingleton Group strata of the Craven inliers. Excluded from this report are the volcanic, volcaniclastic and intrusive igneous rocks of this region which were included within an earlier report (Millward, 2004). The framework presented herein results from the modern 1:10 000-scale geological mapping undertaken by the British Geological Survey and its university partners during the Lake District Regional Geological Survey, which occurred mostly from 1981 until 2005. This account seeks to summarise the current status of the lithostratigraphy of these strata and to resolve some of the remaining ambiguities.

1.1 TECTONIC SETTING

The Early Palaeozoic geological history of northern England is intimately associated with closure of the Iapetus Ocean and the collision of the ancient continents of Laurentia and Avalonia that it once separated. The ocean was initiated during late Neoproterozoic times and grew to a likely maximum width in excess of 1000 km by the end of the Cambrian Period. Thereafter, subduction at its margins wrought its eventual destruction and drove the series of collisional events that built up the Caledonian Orogen, a major tectonic zone that can be traced from Scandinavia, through Britain and Ireland, and on into Greenland and maritime North America (e.g. Soper et al., 1992; Pickering and Smith, 1995; Cocks et al., 1997; Cocks and Torsvik, 2002).

To the north of the Iapetus Ocean, in tropical and subtropical latitudes, lay the continent of Laurentia. The Archaean and Proterozoic crystalline basement rocks of Scotland formed a part of this continent, and subduction of Iapetus oceanic crust beneath its margin led to the sequential accretion of oceanic terranes. The history of the ocean's destruction at this northern margin is recorded in these: for example, in the Tremadoc to Arenig, Ballantrae Complex ophiolite, the obduction of which occurred at about 470 Ma during the collision of a volcanic arc complex with the continental margin. This collision provoked the Grampian Event of the polyphase Caledonian Orogeny. Thereafter, continued Late Ordovician to mid Silurian subduction at the northern margin of the Iapetus Ocean is demonstrated by the Southern Uplands accretionary thrust belt (Clarkson et al., 2001).

At the southern margin of the Iapetus Ocean, at a latitude of about 60° south, lay the shores of the Gondwana continent from which a small fragment broke away early in Palaeozoic times (McKerrow et al., 1991; Cocks and Fortey, 2009). This fragment, known as Avalonia, drifted north, towards Laurentia, as the intervening Iapetus Ocean closed. In northern England, Lower Palaeozoic inliers (Figure 1) reveal parts of the northern margin of Avalonia and show how it developed in response to the changing geotectonic regime, compounded by the arrival of Baltica from the east. The oldest rocks present in the region are likely to be those from the enigmatic and possibly Neoproterozoic, metasedimentary Ingleton Group (Soper and Dunning, 2005). This unit is exposed a little to the south-east of the Lake District in small inliers around the Craven district. Within the main Lake District inlier the oldest rocks seen are the Tremadoc to Llanvirn, turbiditic mudstone and sandstone of the Skiddaw Group (a broad correlative is the Manx Group in the Isle of Man) that were deposited in extensional basins along the continental margin of Avalonia as it rifted from Gondwana (Cooper et al., 2004). As much as 5000 m of strata accumulated, with much evidence for large-scale slumping of the unconsolidated sediment.

Along other parts of the Avalonian continental margin, and as close to the Lake District as north Wales, there is evidence from volcanic rocks that southward subduction of the Iapetus Ocean commenced during late Cambrian times (Kokelaar, 1988), but in the Lake District inlier the earliest subduction-related magmatism was Late Ordovician in age. As a precursor to volcanic activity, the deep-marine strata of the Skiddaw Group were uplifted and eroded. Then, during a short-lived but violently active Late Ordovician volcanic interval (<5 million years culminating at about 450 Ma; Millward and Evans, 2003), the Borrowdale and Eycott volcanic groups were erupted. These groups now crop out, respectively, to the south and north of the main Skiddaw Group inlier, a disposition inherited from their having originally built up within opposing half-graben, each originally 40 to 50 km wide (Millward, 2002). Several thousand metres of lava, ignimbrite and volcaniclastic sediment were preserved in a series of volcanic calderas. Beneath the volcanoes, granitic plutons were emplaced, coalescing to form the Lake District batholith.

Thermal subsidence followed the cessation of Late Ordovician magmatism, allowing marine transgression across the eroded remains of the Borrowdale and Eycott volcanoes during Late Ordovician times (Barnes et al., 2006). The Dent Group, the lowest part of the Windermere Supergroup and of Ashgill age, encompasses a range of shallow marine lithofacies with some volcanic rocks produced during the final throes of volcanicity (Lawrence et al., 1986; Millward et al., 2000; Rickards and Woodcock, 2005). It was followed during the Llandovery by accumulation in deeper water of a thin condensed sequence of marine mudstone, the Stockdale Group. Meanwhile, the convergence of Laurentia and Avalonia continued, with the Southern Uplands accretionary thrust terrane testament to the Caradoc to Wenlock subduction of Iapetus Ocean crust beneath the margin of Laurentia (Oliver et al., 2002). As the ocean narrowed, the fossil faunas preserved at its opposing margins became progressively more cosmopolitan (Cocks and Fortey, 1982).

The inevitable collision occurred at some time during mid Silurian times, but was a tectonic anticlimax (Soper et al., 1992). There was instead something of a tectonic continuum, as the Southern Uplands accretionary thrust terrane over-rode Avalonia and continued southwards as a foreland fold and thrust belt. A load-induced, flexural foreland basin advanced ahead of the thrust front and was an influential control on sedimentation during the accumulation of the middle and upper Silurian parts of the Windermere Supergroup (Soper and Woodcock, 2003). Subsidence and sedimentation rates reached their maxima during late Silurian (Ludlow) times with deposition of the Coniston Group, up to 2000 m or more of turbidite sandstone that accumulated during the course of less than two graptolite biozones – probably no more than 1 million years (Kneller, 1991; King, 1994). Thereafter, the upper Ludlow and Pridoli succession reflects a slowing of the subsidence rate and a commensurate filling of the sedimentary basin. It would seem that convergence between Laurentia and Avalonia ceased, the foreland basin failed to migrate southwards, and isostatic adjustments reversed the earlier effects of loading.

In the transtensional tectonic regime during Early Devonian times, strike-slip basins opened across the region and were filled with the clastic, terrestrial sediments of the Old Red Sandstone lithofacies. It is something of a geological paradox that the Lower Palaeozoic rocks of the Avalonian margin did not experience their maximum deformation as a result of the Laurentia–Avalonia collision. Instead, that event ground to a halt and it was not until the Mid Devonian, Acadian Orogeny that pervasive deformation and cleavage formation occurred (Soper and Woodcock, 2003). Stratigraphical constraints, the relationship of cleavage fabrics to dated granite intrusions, and dating of white mica formed within the cleavage planes, all combine to suggest an Emsian age, about 400 Ma. The metamorphic grade attained then, albeit very low, still implies a substantial overburden, now eroded, of nonmarine Old Red Sandstone strata. A minimum 3500 m pretectonic thickness for this cover has been estimated in the southern Lake District, and tectonically driven subsidence of the underlying Avalonian crust is clearly required to accommodate such a thickness of nonmarine sediment. The Acadian Orogeny was probably initiated by collision of another rifted Gondwana fragment, Armorica, with the south side of Avalonia (Woodcock et al., 2007).

2 Correlation and biostratigraphical framework

2.1 CHRONOSTRATIGRAPHY

The internationally agreed global standards for Ordovician and Silurian chronostratigraphy are shown in Tables 1 and 2 respectively, from the International Commission on Stratigraphy (http://stratigraphy.org/). The radiometric ages for the system and series boundaries are from the International Stratigraphic Chart (2009) which may be downloaded from the website. Whereas the GSSPs for the series within the Silurian are, with one exception (Pridoli), located in the UK and were agreed some time ago, all of those for the Ordovician have only recently been agreed and are sited elsewhere in the world. Hence, whereas the global standard for the Silurian is in wide use in the UK (Cocks et al., 1992), the local series and stages for the Ordovician are still commonly used. This correlation issue is addressed by Cocks et al. (2010) and their proposals are used in Table 1. Because of the difficulties in applying some of the international Stages accurately, Cocks et al. recognise that traditional divisions will continue to be used, as they are throughout this report. The classical British chronostratigraphical divisions were revised by Fortey et al. (1995) and this formed the foundation of the Geological Society's revised correlation chart (Fortey et al., 2000). Cocks et al. (2010) recommend that the revised British Series are henceforth regarded as Regional Stages and the British Stages as Regional Substages. In consequence, there seems to be no place in the new scheme for the long used British subdivisions of the Caradoc. These have proved to be particularly helpful in northern England, though Fortey et al. (1995) grouped them into broader divisions. In view of their extensive use in the literature, the classical British Caradoc substages are included in Table 1 and in the lithostratigraphical definitions.

2.2 BIOSTRATIGRAPHY

2.2.1 Ordovician

Biostratigraphy and correlation of the Ordovician strata of the British Isles are based traditionally on a system of graptolite biozones (Table 1) (Zalasiewicz et al., 2009), which are supplemented locally by schemes based on acritarchs and shelly faunas. Fossiliferous sedimentary strata of early Tremadoc and late Llanvirn to early Caradoc age are not preserved in northern England, though the subaerial Borrowdale Volcanic Group was emplaced during the latter interval, probably during the Burrellian (Molyneux, 1988; Millward and Molyneux, 1992; Millward, 2002). Correlation within the upper Tremadoc to Llanvirn Skiddaw Group was facilitated greatly by the use of graptolite biozonation, aided particularly in the graptolite-poor parts of the succession by a sequence of acritarch biozones (Cooper et al., 2004). Fewer biostratigraphically significant graptolites have been recorded from the Manx Group in the Isle of Man, and here correlation has most recently relied upon the acritarch biozonation (Molyneux, 1979, 1999, 2001; Chadwick et al., 2001).

In northern England, the Ashgill Dent Group strata are dominated by shelly faunas. In the Cautley and Dent inliers, location of the type Ashgill Series in Great Britain, Ingham (1966) established eight biozones on the basis of these, mainly trilobite, faunas. Subsequently, Ingham and Wright (1970) divided the type Ashgill succession into four stages, with his shelly zones 1 to 4 within the Cautleyan, zones 5 to 7 in the Rawtheyan and the uppermost, zone 8, in the Hirnantian. Ingham's zones have proved of particular utility in subsequent studies (e.g. McNamara, 1979) of these strata throughout the region and these zones are included in Table 1.

Graptolites from Ashgill strata in northern England have been rarely recorded, except for the particularly rich assemblage reported by Rickards (2002) from Zone 6, within the Rawtheyan. From these he concluded that the *linearis* Biozone was longer than previously understood, and that it included the late Caradoc and Rawtheyan. In consequence, the stratigraphical space for the

remaining Ashgill biozones, particularly the *complanatus* and *anceps* biozones is significantly diminished and their status placed in doubt (see also Zalasiewicz et al., 2009).

The upper Caradoc to Ashgill Cautley Mudstone Formation and succeeding Cystoid Limestone Member of the Ash Gill Mudstone Formation have yielded a diverse ostracod fauna of more than 30 species (Williams et al., 2001). Williams et al. recognised several species of short duration that have enabled a local ostracod biostratigraphy to be established. Substantial numbers of these species are common to palaeocontinental Baltica and fewer but significant numbers also to Laurentia, facilitating wider correlation of these strata.

2.2.2 Silurian

Biostratigraphy and correlation of Silurian strata in the British Isles are largely based on a system of graptolite biozones (Cocks et al., 1992; Zalasiewicz et al., 2009). The graptolite biozones listed in Table 2 for northern England are based on Rickards (1989), with further refinements to the Gorstian and Ludfordian biozones by Rickards and Woodcock (2005). This scheme was used in recent Lake District literature; its correlation with the recent revisions by Zalasiewicz et al. (2009) is shown in Table 2.

One significant difference between the two schemes is the position of the Llandovery–Wenlock boundary. Zalasiewicz et al. (2009) place this tentatively at the base of the *murchisoni* Graptolite Biozone rather than at the base of the underlying *centrifugus* Biozone as previously. This is based on micropalaeontological evidence in the type Llandovery–Wenlock boundary succession (Mullins and Aldridge, 2004). However, Zalasiewicz et al. commented that the *centrifugus* and *murchisoni* biozones are often indistinguishable.

3 Lithostratigraphical framework

The Lower Palaeozoic strata in the Lake District were divided originally into three principal units by Jonathan Otley (1820). Though the names of the units and their sub-units have changed, and their genetic interpretations have evolved, often subtly, these broad divisions reflect the geological evolution of the region very well, even today. As a result of a considerable body of research, culminating in the BGS Lake District Regional Geological Survey from 1981 to 2005, Otley's (1820) original divisions are now enshrined in a well established lithostratigraphical framework comprising the Skiddaw Group, the Eycott and Borrowdale volcanic groups, and the Windermere Supergroup (Figure 2). The oldest unit is the Skiddaw Group, a Lower and Middle Ordovician succession comprising more than 5000 m of deep marine turbiditic mudstone and sandstone. These rocks are overlain by the geographically separate Upper Ordovician (Caradoc), subaerial, subduction-related Eycott and Borrowdale volcanic groups, respectively at least 3000 and 6000 m thick. The uppermost division is the Windermere Supergroup, spanning the latest Ordovician and Silurian, and comprising near shore and shelf calcareous mudstone and limestone at its base, and overlain by a succession of turbiditic sandstone and siltstone interbedded with hemipelagic mudstone, probably more than 5000 m thick and representing the infill of a flexural foreland basin (Figure 3). The base of the geological succession in the Lake District is nowhere seen and regional, angular unconformities separate the major divisions, though only the one at the top of the Windermere Supergroup shows evidence of orogenesis (Figure 4). Controversies have enriched the development of both the lithostratigraphy and of our understanding of the nature of the relationship between the various units. However, any summary here of the historical development of ideas on Lake District geology would be wholly inadequate in the light of Oldroyd's (2002) intricate chronicle to which readers wishing to explore this aspect are referred.

In the Isle of Man, the Manx Group is the equivalent of the Skiddaw Group (Stone et al., 1999), and may correlate with the Ribband Group in south-east Ireland (McConnell et al., 1999). However, though lithologies are similar, the stratigraphical detail is different in each of these areas and they were probably each deposited in separate sedimentary basins. Recently, Silurian rocks have been recognised in the Isle of Man and assigned to the Dalby Group by Morris et al. (1999).

The Ingleton Group is also included in this account because many authors have correlated it with the Skiddaw Group. However, neodymium isotope data show that these groups have a distinct provenance (Stone and Evans, 2002), and the deformation and metamorphic history further suggest that the Ingleton Group may be significantly older than the Skiddaw Group (Soper and Dunning, 2005), despite the extant early Ordovician acritarch age obtained from a single sample from the Beckermonds Scar Borehole (Wilson and Cornwell, 1982), close to the Ingleton Group outcrop.

The supergroup and groups that comprise this framework are described below; component formations and members are set out in the succeeding sections of this report. The lithostratigraphy of the Skiddaw and Manx groups is attributable with little modification to Cooper et al. (1995, 2004) and Chadwick et al. (2001) respectively, whereas that for the Windermere Supergroup is based largely on the work of Kneller et al. (1994), with additional information from Rickards and Woodcock (2005) and various Geological Survey publications. The reader is referred to companion reports in the current series for information on the volcanic lithostratigraphy and igneous lithodemic framework (Millward, 2004; Gillespie et al., 2008). In sections 4 to 11 of the report reference to BGS maps is given where appropriate, using the map name; the corresponding map number may be found in Figure 1.

3.1 SKIDDAW GROUP (SKG)

The Skiddaw Group is named after the eponymous mountain in the northern Lake District that is made up from these rocks. The group consists of a succession, probably in excess of 5000 m thick, of bedded, dark grey mudstone and siltstone, along with varying proportions of laminated to thick-bedded sandstone (mainly wacke) commonly amalgamated into packages that attain tens to hundreds of metres in thickness. These are interpreted as deep marine turbidite fan deposits (Moore, 1992; Cooper et al., 2004). The succession also includes a mixed unit of disrupted mudstone and siltstone, with masses of sandstone up to kilometre scale, and interpreted as an olistostrome deposit (Webb and Cooper, 1988; Cooper et al., 2004). The group is possibly late Cambrian to Llanvirn in age and is the oldest known unit in the Lake District. The base is not seen and the top is marked by a major unconformity in which all of its constituent formations are overstepped by Caradoc volcanic rocks of the Eycott and Borrowdale volcanic groups (Millward and Molyneux, 1992; Millward, 2004).

These rocks have been referred to as the Skiddaw 'Slates' since Otley (1820, 1823) and Sedgwick (1832). Jackson (1978) formalised this as the Skiddaw Group, but in the same book, Wadge (1978) included what is now designated as the Tarn Moor Mudstone Formation within his Eycott Group. This definition of the Eycott Group was not accepted by Millward and Molyneux (1992), and the definition of the Skiddaw Group, including the Tarn Moor Mudstone Formation, adopted herein is that of Cooper et al. (1995).

Skiddaw Group strata crop out within the main Skiddaw Inlier in the northern Lake District, also in the Black Combe (e.g. Helm, 1970; Johnson et al., 2001) and Furness (Rose and Dunham, 1977) inliers in south Cumbria, in the Cross Fell Inlier (Shotton, 1935; Burgess and Wadge, 1974) and in the Teesdale Inlier in the north Pennines (Johnson, 1961; Lister and Holliday, 1970). Cleaved mudrocks assigned to the Skiddaw Group have also been recorded from beneath basal Carboniferous rocks in the Wrentnall Shaft [NY 8604 3054] of Cow Green Mine, near to the Teesdale Inlier, and from deep boreholes (Figure 1) at Allenheads in south Northumberland (Burgess, 1971) and at Roddymoor in County Durham (Woolacott, 1923). Skiddaw Group rocks therefore probably form the 'basement' beneath much of northern England.

Except in the smaller inliers, the Skiddaw Group has been almost completely divided into component formations, recognising a succession of sandstone-dominated turbidite packages within what may be regarded as background pelagic sedimentation. However, one fault-bound area within the main, Skiddaw Inlier that lies subjacent to the Eycott Hill outcrop of the eponymous volcanic group, is shown on the Cockermouth (sheet 23) and Keswick (sheet 29) 1:50 000 geological survey maps as Skiddaw Group, undivided. Here were found possibly the oldest rocks within the group, containing likely late Cambrian acritarchs (Millward and Molyneux, 1992).

Macrofossils are not abundant in the group, though extensive collections of widely distributed graptolites have formed the basis of biozonation (e.g. A W A Rushton, in Cooper et al., 2004). Few other macrofossils have been found other than trilobites, the diverse assemblage of which indicates deposition in deep marine water on the margin of Gondwana (Fortey et al., 1989). More recently the microfossils, in particular acritarchs, have proved useful biostratigraphical markers, in conjunction with the graptolites (S G Molyneux, in Cooper et al., 2004).

The Latterbarrow Sandstone Formation and the Redmain Sandstone have been traditionally included within the Skiddaw 'Slates', but are excluded from the current framework, each for separate reasons. The former unit was first recognised by Ward (1876), and subsequent work by Eastwood et al. (1931), Jackson (1961, 1978), Wadge (1978) and Moseley (1984) placed it as the uppermost unit of the Skiddaw 'Slates'. However, Simpson (1967) and Allen and Cooper (1986) considered the sandstone to be the basal unit of the Borrowdale Volcanic Group, where it currently resides (Millward, 2004). The Redmain Sandstone was described originally by Eastwood (1927) and Eastwood et al. (1931), and equated with the Latterbarrow Sandstone. This

was not supported through subsequent petrological work by Allen and Cooper (1986), who established a separate Redmain Formation. However, though these rocks are geochemically distinct, Cooper et al. (2004) considered them to represent highly weathered sandstone belonging to the Loweswater Sandstone Formation, and use of the term Redmain Sandstone was discontinued.

The **Tailbert Sandstone Formation** (Bell, 1997) occupies a stratigraphical position similar to that of the Latterbarrow Sandstone Formation, separated from both the Skiddaw Group and the Borrowdale Volcanic Group by unconformities. Though Bell (1997) did not assign a parent to the formation, Millward et al. (2003) placed it in the Skiddaw Group, though Cooper et al. (2004) considered this assignment to be tentative. Reconsideration of the main features of the Tailbert Sandstone Formation, such as its volcaniclastic composition and unconformable basal and upper contacts, has led us to conclude herein that the formation might more appropriately reside within the Borrowdale Volcanic Group, thus recognising the parallels with the Latterbarrow Sandstone Formation. Since the Tailbert Sandstone Formation was not defined by Millward (2004), the full definition of the unit is included as Appendix 4 of this report.

3.2 MANX GROUP (MANX)

The term Manx Group was introduced by Simpson (1968) to replace the Manx Slate Series which had been in use since it was first described in the Isle of Man by Lamplugh (1903). The definition was modified by Woodcock et al. (1999) to exclude the succession of rocks that includes a distinctive hemipelagic facies, and shown by Howe (1999) to be of Silurian age; the Manx Group is therefore entirely Ordovician in age.

Strata comprise units of mudstone, siltstone and sandstone, mostly deposited from turbidite flows. Neither the base nor the top of the group is proved. The exposed thickness is likely to exceed 5000 m, though the true total is difficult to estimate because of remaining uncertainties in our understanding of the structure. Lamplugh (1903) identified a small number of named units within his otherwise undivided Manx Slate Series. Further subdivisions were established by Simpson (1963). However, the available biostratigraphical data can not be reconciled with Simpson's stratigraphical and structural model, and the present stratigraphy is that established by Chadwick et al. (2001) during the resurvey of the island; based on further work, this rationalised the seven structurally separated sequences established by Woodcock et al. (1999). The group is depicted as entirely divided on the BGS 1:50 000-scale geological map, except in the north of the island where it is obscured by a thick cover of superficial deposits.

Manx Group rocks have not proved very fossiliferous, with only a handful of graptolites reported (Rushton, 1993). These indicate a late Tremadoc to early Arenig age for the group, but are insufficient to be of assistance in subdividing the succession. Major advances in interpreting the structure and stratigraphy of the group have been provided by studies of the more abundant acritarch microflora (Molyneux, 1979, 1999, 2001), particularly in the light of work carried out in the Lake District. A similar biostratigraphical scheme based on acritarchs has been established for both the Manx and Skiddaw groups, which can now be closely correlated (Cooper et al., 1995, 2004). A broad regional correlation has also been made with the Ribband Group in south-east Ireland (McConnell et al., 1999).

3.3 INGLETON GROUP (ING)

A succession, at least 3000 m thick and consisting of bedded turbiditic sandstone and siltstone with sporadic intraformational conglomerate, is exposed in the Craven inliers at Chapel le Dale and Horton in Ribblesdale. Rastall (1906) proposed the name Ingletonian Series for these rocks to differentiate them from Lower Palaeozoic rocks of the Lake District with which correlation had been made during much of the 19th century. This name, commonly shortened to 'Ingletonian', was widely used until Ingham and Rickards (1974), Dunham and Wilson (1985)

and Arthurton et al. (1988) designated these rocks as the Ingleton Group, in line with modern stratigraphical practice.

The base of the group is not proved and its top is overlain unconformably by rocks of the Windermere Supergroup and by rocks of Carboniferous age. The age of the Ingleton Group has proved enigmatic, with opinion varying between Precambrian (e.g. Rastall, 1906) and Early Palaeozoic (e.g. Dakyns et al., 1890; O'Nions et al., 1973; Arthurton et al., 1988) during the more than 200 years that have elapsed since Playfair (1802) first described these rocks and the unconformity at Thornton Force [SD 695 753]. A succinct summary of previous research is provided by Soper and Dunning (2005) in their recent description and interpretation of the Ingleton Group.

Apart from an enigmatic trace fossil described by Rayner (1957), the Ingleton Group has proved unfossiliferous, and the assignment of an Early Palaeozoic (Arenig) age hinges on the record of poorly preserved but identifiable palynomorphs from a single sample of similar rocks from the Beckermonds Scar Borehole (Figure 1), sited about 8 km to the north of Horton (Wilson and Cornwell, 1982). However, this age has proved hard to reconcile with the structural and metamorphic history of the rocks which record major pre-Acadian folding and metamorphic events that are unknown elsewhere in northern England (Soper and Dunning, 2005; Kemp and Merriman, 2009). Similarities in lithofacies and provenance with Neoproterozoic rocks in the English Midlands and Welsh Borderland suggest that the Ingleton Group may also be of this age, though a Cambrian to early Ordovician age cannot yet be discounted.

Soper and Dunning (2005) defined three formations within the uppermost 450 m of the succession, but left the remainder undivided. The units are, in ascending order, Baxengill, Pecca and Skirwith formations. These units appear to have a very restricted surface distribution and have not yet been adopted on Geological Survey maps, but do form the basis of a lithostratigraphy. The group is not described further in this report.

3.4 WINDERMERE SUPERGROUP (WIN)

The term Windermere Supergroup was introduced by Kneller et al. (1994) for the folded and cleaved marine carbonate and clastic sedimentary rocks that lie above the unconformity at the top of the Caradoc volcanic rocks in the Lake District and adjacent inliers in northern England, but below unconformably overlying Devonian Old Red Sandstone or basal Carboniferous rocks. The oldest strata, assigned to the Dent Group, are Late Ordovician in age, whilst the remainder are Silurian. Moseley (1984) first combined all the rocks of this age range into a single unit, the Windermere Group, which forms the basis of the current definition.

Kneller et al. (1994) defined three groups (Dent, Stockdale, Coniston) within the Supergroup, leaving the Wenlock and upper Ludlow to Pridoli formations 'floating'. However, in preparing regional syntheses such as the new editions of the *Geology of England and Wales* (Brenchley and Rawson, 2006) and of the *British Regional Geology of Northern England* (Stone et al., 2010), it has proved useful to combine the remaining units into two other groups (Tranearth, Kendal), such that the Supergroup entirely comprises formally defined groups, each representing characteristic successions (Figures 3, 4).

At the time when Kneller et al. (1994) defined the supergroup, Silurian rocks were unknown from the Isle of Man. Subsequently, Wenlock rocks have been described from the island and assigned to the Dalby Group (see below). The clear similarities in lithology, age and sediment provenance of these rocks with the Tranearth Group in the Lake District means that the definition of the Windermere Supergroup should be extended to include the Dalby Group.

3.4.1 Dent Group (DNT): Caradoc and Ashgill

Kneller et al. (1994) introduced the name Dent Group for the Upper Ordovician strata in the Lake District and adjacent inliers that contain a shelly benthic fauna; the strata constitute the

oldest group within the Windermere Supergroup. The name was chosen by Kneller et al. in recognition of the almost unbroken Caradoc and Ashgill succession in the Dent and Cautley inliers (Ingham, 1966). Historically, the Dent Group rocks have been referred to as the Coniston Limestone, but this term was abandoned by Kneller et al. in their revision, to avoid duplication of the geographical epithet (cf. Coniston Group). Coniston Limestone was first used by Sedgwick (1845; 1846a, b), before becoming the Coniston Limestone Series of Aveline and Hughes (1872), and Marr (1892a, 1916), the Coniston Limestone Group of McNamara (1979), and the Coniston Limestone Formation of Moseley (1984) and Lawrence et al. (1986).

Components of the Dent Group occur in the northern and southern Lake District, and in the Furness, Cross Fell, Dent and Cautley, and Craven inliers. The group comprises a varied assemblage of marine clastic rocks, calcareous siltstone and limestone, and includes a number of volcanic units. The group is wholly divided into formations, but many are thin and so, on many of the Geological Survey maps, the group is depicted undivided, or partially divided. Comparison between the scheme summarised here and previous lithostratigraphical units is given by Kneller et al. (1994), Lawrence et al. (1986), and Rickards and Woodcock (2005). The type area is defined as the Cautley and Dent inliers [SD 700 905 to SD 698 900] (Ingham, 1966; Rickards and Woodcock, 2005).

The base of the Dent Group is diachronous across the unconformity on the underlying Caradoc volcanic rocks (Brenchley and Rawson, 2006, fig. 5.15). The oldest rocks in the Dent Group are Longvillian, belonging to the Drygill Mudstone Formation, which occurs in the northern Lake District, and to the basal part of the Dufton Mudstone Formation in the Cross Fell Inlier. In the Cautley and Dent inliers, the lowest part of the Cautley Mudstone Formation is Onnian (Ingham, 1966), whilst in the southern Lake District the onset of Dent Group sedimentation began during Cautleyan times. In the Craven inliers the base of the group is locally diachronous from the Cautleyan to basal Rawtheyan. At the top of the group an abrupt transition into distinctive mudstone of the overlying Stockdale Group is seen at the base of the Spengill Mudstone Member of the Skelgill Mudstone Formation.

The mudstone-dominated successions in the Cross Fell, and Cautley and Dent inliers are up to 450 and 370 m thick respectively, whereas the mainly carbonate part of the succession in the Lake District varies from 20 to about 120 m (Burgess and Holliday, 1979; Millward et al., 2000). However, thickness in the Lake District is inflated locally by the inclusion of thick basal units of conglomerate and sandstone that reach 580 m in the Ulverston area and 685 m in the Kentmere to Longsleddale area, though the latter thickness also includes up to 180 m of extrusive volcanic rocks (Lawrence et al., 1986; Johnson et al., 2001).

The lithofacies and fauna within the Dent Group represent a transgressive succession of shallow marine shelf sediments that encroached across the eroded, irregular unconformity at the top of the Borrowdale Volcanic Group. In the southern Lake District, four depositional cycles are present, each with a non-sequence beneath its base representing emergence and erosion, followed by deposits indicative of submergence in increasing water depth (Kneller et al., 1994). In the Cross Fell and Cautley and Dent inliers, the first three cycles are represented by the Dufton and Cautley formations which were deposited continuously in deeper, oxygenated marine conditions (Rickards and Woodcock, 2005).

3.4.2 Stockdale Group (STK): uppermost Ashgill (Hirnantian in part) and Llandovery

The term Stockdale Group was introduced by Kneller et al. (1994) to include the mudstone and siltstone sequence of latest Hirnantian and Llandovery age which occurs throughout the Lake District, Cross Fell, Cautley and Dent, and Craven inliers. Harkness and Nicholson (1868) first identified the strata that were collectively named the Stockdale Shales by Aveline and Hughes (1872), with the component divisions named by Marr and Nicholson (1888), as the Skelgill and Browgill beds. These terms became firmly established through adoption by subsequent authors, including Blackie (1933), Furness et al. (1967), Ingham and Rickards (1974) and Ingham et al.

(1978). Stockdale Shales Formation was introduced by Moseley (1984), but Lawrence et al. (1986) preferred instead to imply formational status for the Skelgill and Browgill beds. Kneller et al. (1994) formalised these as the Skelgill and Browgill formations of the Stockdale Group.

Despite previous usage of the Lake District term Stockdale Shales in the Craven inliers by Marr (1887), and King and Wilcockson (1934), the term Crummack Formation was introduced for this sequence by Arthurton et al. (1988) and adopted by Kneller et al. (1994). Arthurton et al. (1988) divided the formation into the Hunterstye and Capple Bank members which are direct correlatives of the Skelgill and Browgill formations. However, Kneller et al. (1994) separated out the basal carbonate rocks from the Hunterstye Member as the 'Spengill Member'. These basal rocks are undoubtedly equivalent to the Spengill Mudstone Member of the Skelgill Mudstone Formation in the Lake District, but such a member cannot reside in two formations. With such clear correlation with the Stockdale Group, we consider that use of the Lake District terms in the Craven inliers should be reinstated and recommend that use of the terms Crummack Formation and its constituent members is discontinued.

The lower boundary of the group coincides with the base of the Skelgill Mudstone Formation and the upper boundary is defined by the base of the overlying Brathay Mudstone Formation (Tranearth Group). As the group is wholly divided, the stratotype is defined by those of the constituent formations. Thickness in the southern Lake District is 40 to 120 m, whereas up to 140 m are present in the Howgill Fells, but only 35 m in the Craven inliers. The succession represents deposition from hemipelagic fallout or low-concentration turbidity flows in the marine environment with fluctuating oxygen concentrations.

3.4.3 Tranearth Group (TNTH): Wenlock to lower Ludlow (lowest Gorstian)

Kneller et al. (1994) did not group the Wenlock to lower Ludlow strata formally. However, following an earlier (unpublished) version of their scheme, the term 'Tranearth Subgroup' was used in the Geological Society's Silurian correlation chart (Cocks et al., 1992) to refer to the Brathay and Coldwell formations. An updated definition including the Wray Castle Formation was used by King (1992, 1994), and Soper (1999). The group was defined formally by Rickards and Woodcock (2005). The succession was included as part of Sedgwick's Coniston Flags (Sedgwick, 1845; 1846b, 1852). Later, Marr (1892b, 1916) redefined the Coniston Flags to consist of the Brathay Flags and his Coldwell Beds, which includes what is now the Wray Castle Formation; thus Marr's Coniston Flags are equivalent to the Tranearth Group. In Furness, the Harlock Grits and lower part of the Horrace Flags of Rose and Dunham (1977) encompass much of what is herein included within the Tranearth Group.

The succession is dominated by laminated hemipelagic mudstone and siltstone (Brathay and Wray Castle mudstone formations) that record a background accumulation of anaerobic organic mud with periodic input of turbiditic sand. Interbedded with these are a unit of calcareous siltstone (Coldwell Siltstone Formation) and units of turbiditic sandstone (Birk Riggs Sandstone Formation in the south-west Lake District, and the Austwick Sandstone Formation in the Craven inliers). From Ulverston to Shap the thickness varies between 450 and 1110 m, whereas only 260 m are present in the Howgill Fells.

The group is represented in all of the inliers, though in Cross Fell only the oldest unit (Brathay Mudstone Formation) is present. The nomenclature is distinct in the Craven inliers (Arthurton et al., 1988), reflecting the subtle differences in lithofacies. As the group is wholly divided, the constituent formations define the overall stratotype. The base of the group coincides with that of the Brathay Mudstone Formation. The upper boundary is defined by the diachronous base of the overlying Coniston Group (see below).

3.4.4 Dalby Group (Isle of Man) (DALBY): Wenlock

The Dalby Group is the only Silurian unit represented in the Isle of Man and contains a single formation of late Wenlock age, the Niarbyl Sandstone Formation. The Dalby Group was

established by Morris et al. (1999), following Howe's (1999) determination of a Silurian fauna within the sandstone sequence of the Niarbyl Sandstone Formation in the west of the island. Previously, the Niarbyl Sandstone Formation had been correlated with the Lonan Sandstone Formation (Manx Group) and presumed to be Ordovician. The base and top of the Dalby Group are nowhere proved and its definition is that of the Niarbyl Sandstone Formation.

The distinctive laminated hemipelagic facies interbedded with the sandstone lithofacies is typical of middle Silurian successions in north-west England, south-west Scotland and Ireland. The Niarbyl Sandstone Formation is biostratigraphically equivalent to the Birk Riggs Sandstone Formation in the Lake District and the compositions of the sandstones are similar (Chadwick et al., 2001).

3.4.5 Coniston Group (CTG): Ludlow (middle Gorstian)

The name 'Coniston Grits' was introduced by Sedgwick (1845) and is engrained in Lake District lithostratigraphy (Aveline and Hughes, 1872; Marr, 1878, 1892b, 1916; Blackie, 1933), though the current definition of the Coniston Group by Kneller et al. (1994) and adopted herein differs significantly from that proposed by Sedgwick. The main difference is that the base of the Coniston Group is taken lower in the succession and includes Grit band 2 of Aveline and Hughes (1872, 1888). This definition originated with Norman (1963; Coniston Grit Group), and was followed by Furness et al. (1967; Coniston Grits), and by Moseley (1984) and Lawrence et al. (1986) (Coniston Grit Formation). Kneller et al. (1994) omitted the lithological qualifier.

The group crops out across the southern Lake District from Ulverston to the Howgill Fells, but it is not present in the Cross Fell Inlier; the lower part is represented in the Craven inliers (Arthurton et al., 1988) by the Studfold Sandstone, Sannat Hall Siltstone and Neals Ing Sandstone formations. No formal type section is defined even though the group is depicted on the Kendal 1:50 000 geological map as undivided over much of the eastern part of the Lake District and Howgill Fells. The constituent formations provide adequate stratotypes.

The principal lithofacies comprising the group are thin- to very thick-bedded fine-, medium- and coarse-grained sandstone, commonly amalgamated into units several metres thick. Variations in grain size, bedding character and other sedimentary structures indicate that the group is composed largely of sand-dominated turbidite deposits. These submarine fan systems have greater extent than those developed during Wenlock times. Dispersal was both towards the south-west along the axial region of the basin and from the north and north-west (Furness et al., 1967; Soper and Woodcock, 1990; Kneller, 1991). Laminated mudstone forms a minor proportion of the group and probably represents hemipelagic deposition. The group is sparsely fossiliferous and bioturbation is not common, though the laminated mudstone units yield a fauna of graptolites and orthocones.

The base of the Coniston Group is taken at the first appearance of sandstone above the Wray Castle Mudstone Formation of the Tranearth Group; this is markedly diachronous in the context of the whole region. In the south-west of the Lake District, from just west of Ulverston [SD 250 760], to the head of Borrowdale [NY 520 060], the base of the group coincides with that of the Gawthwaite Sandstone Formation. However, east of Longsleddale to Shap, the Gawthwaite Sandstone Formation pinches out and the overlying hemipelagic mudstones of the Latrigg Siltstone Formation cannot be distinguished from the Wray Castle Mudstone Formation; thus, here the base of the group is at a higher stratigraphical level (Millward et al., 2010). In the Howgill Fells, the base of the group coincides with the base of the Screes Gill Sandstone Formation (Rickards and Woodcock, 2005). Kneller et al. (1994) speculated on the relationship between the Gawthwaite Sandstone and Screes Gill Sandstone formations, but their equivalence is uncertain; they may well represent deposition in entirely separate turbidite systems. The very thin (3–15 m) Wray Castle Mudstone Formation in the Howgill Fells compared with some 450 m farther west suggests that the Screes Gill Sandstone Formation is perhaps the oldest of the

Coniston Group units. The upper boundary of the group is defined by the base of the overlying Bannisdale Mudstone Formation (Kendal Group).

Thickness of the group varies across the region as a result of the stacking of turbidite fans. In the southern Lake District a broad south-west thickening is seen from 820 m south of Shap to about 2300 m in the Ulverston district. Thickness in the Howgill Fells is 1100–1300 m.

3.4.6 Kendal Group (KNDL): Ludlow (upper Gorstian and Ludfordian) and Pridoli

Kneller et al. (1994) did not group the uppermost units within the Windermere Supergroup that lie above the Coniston Group. However, following informal usage by, for example, Cocks et al. (1992), King (1992, 1994), and Woodcock and Strachan (2000), the term Kendal Group was formally defined by Rickards and Woodcock (2005). Earlier, Moseley (1984) had coined the term Kendal Formation to include the strata that lie above the Bannisdale Formation.

Cropping out throughout the south-eastern Lake District and Howgill Fells, the group is more than 2500 m thick and possibly up to 5000 m, and comprises a lower sequence of graded siltstone–mudstone couplets with locally extensive intercalations of tubiditic sandstone (Bannisdale Mudstone Formation), overlain by massive to convolute laminated and ripple-cross laminated fine-grained sandstone (Kirkby Moor Sandstone Formation). The Kendal Group rocks were deposited in a range of marine environments from basinal in the Bannisdale Mudstone Formation, to storm-dominated shelf conditions in the Kirkby Moor Sandstone Formation; the latter recording the final shallowing and infilling of the foreland basin (King, 1994). Thus, the Kendal Group differs in its scope from all others in the supergroup. However, such a grouping has proved useful in regional syntheses such as the new edition of the *Geology of England and Wales* (Brenchley and Rawson, 2006) and of the *British Regional Geology of Northern England* (Stone et al., 2010).

The base of the group coincides with that of the Bannisdale Mudstone Formation and is therefore gradational from the sandstone-dominated Coniston Group into the interbedded siltstone–mudstone couplets of the Bannisdale Mudstone Formation. The upper boundary is an erosion surface, which is unconformably overlain by Upper Old Red Sandstone Group red-bed rocks or by basal Carboniferous strata.

4 Skiddaw Group

The lithostratigraphy of the Skiddaw Group recommended in this report follows that of Cooper et al. (1995, 2004), which was modified from Cooper et al. (1993). Three distinctive successions are recognised, the first two within the Skiddaw Inlier, which are juxtaposed across the Causey Pike Fault, and the third to the south of the South Borrowdales Lineament (Figure 1). They termed the area to the north as the Northern Fells Belt, in which the Skiddaw Group is overlain unconformably by the Eycott Volcanic Group, and those to the south as the Central Fells Belt and the Southern Lake District inliers where the Skiddaw Group is overlain by the Borrowdale Volcanic Group (Figure 5). Comparable successions are also recognised in the Cross Fell Inlier (Cooper and Molyneux, 1990).

4.1 NORTHERN FELLS BELT

Cooper et al. (1995, 2004) established a succession in this region comprising the three mudstone-dominated units of the Bitter Beck, Hope Beck and Kirk Stile formations, separated by the sandstone units of the Watch Hill and Loweswater formations (Figures 5, 6). Rocks of equivalent age in the Cross Fell Inlier have been assigned to the Catterpallot Formation (Cooper and Molyneux, 1990). A small area of the Northern Fells Belt is classified on the 1:50 000-scale geological maps as 'Skiddaw Group, undivided' (Cooper et al., 2004, p. 41). These strata lie within a fault block subjacent to Eycott Hill: the rocks have yielded acritarchs that may indicate a mid to late Cambrian age, though this remains uncertain (Millward and Molyneux, 1992).

4.1.1 Bitter Beck Mudstone Formation (BBF)

Name

The formation was first recognised as a distinct unit by Molyneux and Rushton (1988) and defined by Cooper et al. (1995). It is the oldest unit within the Northern Fells Belt succession.

Stratotype

The partial type area includes the section about 1 km long of Bitter Beck [NY 1399 3113 to NY 1500 3133], east of Cockermouth, where the top of the formation is exposed. Reference sections include the River Derwent [NY 1142 3116], below Papcastle, west of Cockermouth, and in the River Cocker, at Cockermouth, from the old railway bridge [NY1222 3027] to Double Mills [NY 1183 2959].

Lithology

Thinly laminated, dark grey mudstone, silty mudstone and siltstone, with subordinate (up to about 20 per cent) pale fine-grained sandstone in thinly parallel to wavy laminated beds; the proportion of sandstone units increases markedly towards the top of the formation. Slump folding and dislocations subparallel to bedding are common. Further details of this occurrence are given by Cooper et al. (2004, p. 40–41).

Definition of lower boundary

Not proved. The formation is thrust-faulted over the Kirk Stile Mudstone Formation.

Definition of upper boundary

The Bitter Beck Mudstone Formation is gradational into the overlying Watch Hill Sandstone Formation. The contact is taken at the change from mudstone–siltstone lithofacies to where sandstone predominates.

Thickness

250 m in Bitter Beck, but up to 600 m in a very poorly exposed area south of Cockermouth.

Genetic interpretation

Moore (1992) interpreted the formation to represent distal turbidite fan deposits emplaced during a sea-level high stand or episode of coarse-sediment starvation.

Biostratigraphical characterisation

The type section has yielded taxa indicative of the *murrayi* Graptolite Biozone and the *messaoudensis–trifidum* Acritarch sub-Biozone 1 (Cooper et al., 2004).

Age

Late Tremadoc (Cooper et al., 1995, 2004).

Geographical limits

Skiddaw Inlier, north of the Causey Pike Fault, from Cockermouth to Great Sca Fell.

Maps

Lorton and Loweswater (1:25 000); Maryport, Cockermouth, Whitehaven, Keswick

4.1.2 Watch Hill Sandstone Formation (WHG)

Name

This definition is that formalised by Cooper et al. (1995). Ward (1876) first referred to 'sandy and gritty beds of Watch Hill' and Dakyns et al. (1897) first used the term Watch Hill Grits for these rocks. Later authors, for example Eastwood et al. (1931) Simpson (1967), used this term though Eastwood et al. (1968) shortened it to Grits group.

Stratotype

The type area is defined around Watch Hill [NY 1495 3189], 3 km east-north-east of Cockermouth.

Lithology

Lithic wacke and subordinate lithic arenite interbedded with siltstone and mudstone. The sandstone is fine grained to granular with abundant siltstone and mudstone intraclasts. Normal grading and sole structures are present, but other sedimentary structures are not common. With recognition of the Watch Hill felsites as a sill (Hughes and Kokelaar, 1993) the presence of contemporaneous volcanic rocks within the formation, as suggested by Jackson (1961) may be discounted. Further details of the formation are given in Cooper et al. (2004, p. 41–43).

Definition of lower boundary

The base of the Watch Hill Sandstone Formation is taken in the gradational sequence where sandstone and siltstone predominate over mudstone and siltstone of the underlying Bitter Beck Mudstone Formation.

Definition of upper boundary

The boundary with the overlying Hope Beck Mudstone Formation is taken at the change from sandstone-dominated lithofacies to a mudstone–siltstone succession. The junction is not exposed and can be only inferred to lie within about 20 m near Hewthwaite Hall [NY 1516 3276] and just to the north of Lorton Street road bridge [NY 1225 3040].

Thickness

55 to 800 m.

Genetic interpretation

The formation is considered to represent a major episode of turbidite fan growth and input of large volumes of coarse detritus, possibly during a sea-level low stand (Cooper et al., 2004).

Biostratigraphical characterisation

The formation has yielded taxa indicative of the *murrayi* Graptolite Biozone and the *messaoudensis–trifidum* Acritarch sub-Biozones 2, 3 and 4 (Cooper et al., 2004).

Age

Latest Tremadoc or earliest Arenig (Molyneux and Rushton, 1988).

Geographical limits

Skiddaw Inlier, north of the Causey Pike fault, from Cockermouth to Great Sca Fell.

Regional correlation

These strata are considered to be similar in age to the Catterpallot Formation of the Cross Fell Inlier (Cooper and Molyneux, 1990).

Maps

Lorton and Loweswater (1:25 000); Maryport, Cockermouth, Whitehaven, Keswick.

4.1.3 Hope Beck Mudstone Formation (HBE)

Name

The Hope Beck Slates of Jackson (1961, 1978) were formalised as the Hope Beck Formation by Cooper et al. (1995). The name is after its principal occurrence and type area.

Stratotype

Type area is defined along Hope Beck and on the adjacent east flank of Dodd [NY 168 239 to NY 171 233].

Lithology

Dark grey siltstone and mudstone in laminated and very thin beds, with up to 5 per cent sandstone mainly in thin and medium beds. Sporadic pebbly mudstone beds are also present. Further details are given by Cooper et al. (2004, p. 43–44).

Definition of lower boundary

The base is transitional from laminated siltstone and mudstone into sandstone-dominated lithofacies of the underlying Watch Hill Sandstone Formation. The base is nowhere exposed and can only be inferred within about 20 m.

Definition of upper boundary

The upper boundary is transitional from siltstone–mudstone succession into the overlying sandstone-dominated Loweswater Sandstone Formation. Jackson (1961) defined the boundary on the first occurrence of ‘arenites 3 inches (7.5 cm) or more’ thick.

Thickness

600 to 800 m.

Genetic interpretation

Cooper et al. (2004) interpreted the Hope Beck Formation as a mudstone-dominated turbidite fan in which Moore's (1992) interlobe facies association has been recognised, along with some lobe-fringe sandstones. A relatively high sea-level stand is inferred.

Biostratigraphical characterisation

Sparse occurrences of graptolites indicate the upper part of the *phyllograptoides* Graptolite Biozone and the *varicosus* Biozone; the microfloral biozonation is *messaoudensis–trifidum* Acritarch sub-Biozone 5 and *trifidum–bohemicum* Biozone (Cooper et al., 2004).

Age

Early Arenig (Cooper et al., 1995).

Geographical limits

Skiddaw Inlier, north of the Causey Piker Fault and from Cockermouth to Great Sca Fell.

Maps

Lorton and Loweswater (1:25 000); Maryport, Cockermouth, Keswick.

4.1.4 Loweswater Sandstone Formation (LWF)

Name

The definition herein is that of Cooper et al. (1995) who formalised the Loweswater Flags of previous authors, for example: Dixon (1925); Eastwood et al. (1931); Rose (1955); Jackson (1961, 1978) and Simpson (1967).

Stratotype

The type area includes Hope Beck and the east flank of Dodd [NY1710 2330 to NY 1660 2169] (Cooper et al., 1995).

Lithology

Mainly sandstone with minor mudstone and quartz-rich wacke. The basal beds are mainly thin, and of fine-grained sandstone interbedded with siltstone and mudstone. Bed thickness increases towards the middle of the formation and then decreases through the upper part. Further details of this occurrence are given by Cooper et al. (2004, p. 44–49).

Definition of lower boundary

The lower boundary is gradational from siltstone-mudstone sequence of the underlying Hope Beck Mudstone Formation to a sandstone-dominated sequence. The boundary is exposed on the east side of Dodd [NY 171 233]. Jackson (1961) defined the base on the first occurrence of 'arenites 3 inches (7.5 cm) or more' thick.

Definition of upper boundary

In the upper part of the formation bedding thickness decreases abruptly and the proportion of interbedded mudstone increases to give a laminated facies of sandstone and mudstone with sporadic thin beds of quartz wacke. The top of the formation is taken at the highest thin sandstone bed in the dominantly sandstone part of the succession, above which mudstone–

siltstone of the Kirk Stile Mudstone Formation predominates. The boundary is exposed in a small quarry on Whiteside End [NY 1660 2169] (Cooper et al., 1995).

Thickness

900 m in the north-west of the outcrop; 450 m around Jonah's Gill [NY 190 343], but unknown in the faulted inlier in Mungrisedale.

Genetic interpretation

Cooper et al. (2004) considered that the Loweswater Sandstone Formation represents the 'acme of turbidite fan activity in the Skiddaw Group'. The distributary channel, depositional lobe and interlobe facies associations of Moore (1992) have been recorded.

Biostratigraphical characterisation

The *varicosus* Graptolite Biozone fauna range through much of the sequence, though the upper part has yielded a *simulans* Biozone assemblage. The *Coryphidium bohemicum* Acritarch Biozone has been recorded locally from the lower part of the formation, whereas the *Stelliferidium* aff. *pseudoornatum* Acritarch Biozone is indicated for the upper part (Cooper et al., 2004).

Age

Mid Arenig (Cooper et al., 2004).

Geographical limits

Skiddaw Inlier, north of the Causey Pike Fault.

Maps

Lorton and Loweswater (1:25 000); Cockermouth, Whitehaven, Keswick.

4.1.5 Kirk Stile Mudstone Formation (KST)

Name

The designation of this formation by Cooper et al. (1995) followed the previous definition of the Kirk Stile Slates by Jackson (1978). The formation is named after Kirk Stile, Loweswater [NY 131 209]. These rocks were previously referred to variously as the Kirk Stile Slates, Mosser Slates, Mosser Striped Slates, Mosser–Kirkstile Slates, Blakefell Mudstone, and Sunderland Slates (Dixon, 1925; Eastwood et al., 1931; Rose, 1955; Jackson, 1961; Simpson, 1967; Jackson, 1978).

Stratotype

The type area is west of Keswick, from Winlatter Pass, south-south-east to Sleet How and Outerside [NY 203 245 to NY 214 216].

Lithology

Thinly laminated to very thinly bedded dark grey siltstone and mudstone, locally with lenticular units of lithic wacke. Slump folds and debrites are widespread. Further details are given by Cooper et al. (2004, p. 49–51).

Definition of lower boundary

The base is taken above the uppermost thin sandstone bed in the underlying Loweswater Sandstone Formation at the change into mudstone–siltstone-dominatedlithofacies of the Kirk Stile Mudstone Formation.

Definition of upper boundary

The upper boundary is not seen as these rocks were eroded and overlain unconformably by the Eycott Volcanic Group (Millward and Molyneux, 1992).

Thickness

1500 to 2500 m.

Genetic interpretation

Cooper et al. (2004) interpreted these rocks as mudstone-dominated turbidite fan deposits. The soft-sediment deformation was considered to have been penecontemporaneous with emplacement of the Buttermere olistostrome of the Central Fells Belt.

Biostratigraphical characterisation

The lowest part of the succession is tentatively assigned to the *simulans* Graptolite Biozone, whilst the remainder of the succession ranges through the *victoriae* and succeeding biozones into the *artus* Biozone. The acritarchs present indicate the *Stelliferidium* aff. *pseudoornatum* and *hamata–rarirrugulata* biozones (Cooper et al., 2004).

Age

Arenig to earliest Llanvirn.

Geographical limits

The formation is restricted to the Skiddaw Inlier, north of the Causey Pike Fault, where it is the most extensive rockhead formation.

Maps

Lorton and Loweswater (1:25 000); Cockermouth, Whitehaven, Keswick.

4.2 CENTRAL FELLS BELT

Two formations are recognised in the Central Fells Belt (Figures 5, 6): the Buttermere Formation, a major olistostrome deposit, overlain by a sequence of mudstones comprising the Tarn Moor Mudstone Formation. These are overlain unconformably by the Borrowdale Volcanic Group.

4.2.1 Buttermere Formation (BUF)

Name

This formation was newly defined by Cooper et al. (1995).

Stratotype

A complete section through the formation is not seen and the type area given by Cooper et al. (1995, 2004) is east of Buttermere village, encompassing the water-polished slabs in Mill Beck [NY 1750 1700 to NY 1884 1900], and the area around High Snockrigg and Robinson [NY 187 169 to NY 202 169]. Cooper et al. (2004, p. 51–55) also described a number of other key sections.

Lithology

An heterogeneous accumulation of disrupted, sheared and folded masses of mudstone, siltstone and sandstone turbidites. Two very large such masses near the middle of the formation are formally defined as members: the Goats Gill Member of sedimentary breccia, and the sandstone-dominated Robinson Member.

Definition of lower boundary

The base is not proved and the formation is the oldest known in the Central Fells Belt.

Definition of upper boundary

The upper boundary is tectonic and overthrust by rocks of the Crummock Water aureole. The relationship with the younger Tarn Moor Mudstone Formation is faulted.

Thickness

At least 1500 m.

Genetic interpretation

The formation is interpreted as an olistostrome deposit; the component members are probably large olistoliths (Webb and Cooper, 1988).

Biostratigraphical characterisation

Component masses within the olistostrome deposit have biostratigraphical ages that range from Tremadoc to Arenig. Cooper et al. (2004) drew attention to three significant features: absence of rocks of the *cucullus* Graptolite Biozone which has implications for the timing of emplacement of the olistostrome; the absence of the *messaoudensis–trifidum* Acritarch Biozone flora; and the spatial juxtaposition of beds indicative of widely varying biozones.

Age

Emplacement of the olistostrome is inferred to have occurred during late Arenig times (Cooper et al., 2004).

Geographical limits

The formation lies to the north of the Borrowdale Volcanic Group outcrop and to the south of the Causey Pike Fault. The western limit is unclear: exposures in the River Calder may be Buttermere Formation or a lower part of the succession.

Maps

Lorton and Loweswater (1:25 000); Whitehaven, Keswick, Appleby.

Regional correlation

The Murton Formation of the Cross Fell Inlier has been correlated with the Buttermere Formation (Cooper and Molyneux, 1990).

4.2.1.1 GOAT GILLS BRECCIA MEMBER (GGM)

Name

The name is taken from the type location of the member which was designated by Webb (1992), following the informal use of the term by Webb and Cooper (1988).

Stratotype

The type area is Goat Gills and Goat Crag [NY 1900 1625 to NY 1920 1640], north-east of Buttermere lake.

Lithology

Breccia, mainly of siltstone in a siltstone matrix (Cooper et al. 2004, p. 52).

Definition of lower boundary

The base is not exposed.

Definition of upper boundary

The top is a sharp contact with the overlying Robinson Member: the sequence is inverted.

Thickness

Approximately 100 m.

Age

Probable Tremadocian clasts incorporated into a late Arenig slump deposit.

Geographical limits

Goat Gills to Goat Crag, north-east of Buttermere lake.

Maps

Not shown on published Geological Survey maps.

4.2.1.2 Robinson Sandstone Member (RMN)

Name

The name is taken from Robinson, where this member crops out (Cooper et al., 1995).

Stratotype

The type area is defined in Littledale [NY 210 173 to NY 215 175], where the formation's maximum thickness is present.

Lithology

A set of large sandstone masses (olistoliths) up to 1 km in size, consisting mainly of quartz-rich lithic wacke and granule conglomerate, interbedded with siltstone and mudstone. Further details are given by Cooper et al. (2004, p. 52).

Definition of lower boundary

Locally this unit sharply and conformably overlies the Goat Gills Member [NY 1895 1624] in an inverted sequence, but the lowest beds are highly disturbed. In Goat Gills [NY 1914 1630] the lowest beds are truncated against the underlying unit.

Definition of upper boundary

The Robinson Member is surrounded by an envelope of sandstone-rich Buttermere Formation rocks.

Thickness

About 250 m.

Age

Cooper et al. (2004, p. 53) suggested an early to mid Arenig age for deposition of the sandstone, with disruption and incorporation into a late Arenig slump deposit.

Geographical limits

Several small, isolated outcrops within the Buttermere Formation from Buttermere north-east to Swinside, west of Derwent Water.

Maps

Keswick.

4.2.2 Tarn Moor Mudstone Formation (TMF)

Name

The name Tarn Moor Mudstone was proposed by Wadge et al. (1972) for mudstone of *D. murchisoni* Graptolite Biozone age proved in the Tarn Moor Tunnel. Wadge (1978) included these rocks in his definition of the Eycott Group, but in the same book Jackson (1978) included them in the Skiddaw Group along with the succession proved in the Tailbert–Lanshaw Tunnel described by Skevington (1970). Moseley (1984) formalised these rocks as the Tarn Moor Mudstone Formation and considered them to be the lateral equivalent of the Eycott Group; such a correlation is now unlikely after Millward and Molyneux (1992) demonstrated both an unconformable relationship between the Eycott Volcanic Group and the underlying Skiddaw Group, and that there was no palaeontological basis for the volcanic rocks being of the same age as the Tarn Moor Mudstone Formation. The formal definition herein is by Cooper et al. (1995) and further details are in Cooper et al. (2004, p. 55–58).

Stratotype

A formal type section was not defined by Cooper et al. (1995). The 600 m long section in Mosedale Beck is recommended herein from Cooper et al. (1995) [NY 3556 2386 to NY 3567 2438]. The Tarn Moor Tunnel [NY 4766 2270], which cuts through the youngest known part of the succession (Wadge et al., 1972), is recommended as a reference section.

Lithology

Laminated and thickly laminated mudstone with subordinate siltstone beds in the lower part pass up into mudstone and, locally, siltstone with up to 5 per cent volcaniclastic sandstone and metabentonite; the uppermost part of the formation comprises dark grey to black mudstone.

Definition of lower boundary

The base is not exposed, but these rocks are inferred to overlie the Buttermere Formation unconformably.

Definition of upper boundary

The top is an erosion surface, succeeded unconformably by the Borrowdale Volcanic Group.

Thickness

1000 to 1500 m.

Genetic interpretation

The lithological similarities with the Kirk Stile Formation suggest similar origins. However, the occurrence within the Tarn Moor Mudstone Formation of metabentonite beds implies the direct input of volcanic ash, probably from distant volcanoes. In addition, some lithic clasts within the formation have a volcanic provenance (Cooper et al., 2004).

Biostratigraphical characterisation

The oldest beds proved contain an acritarch flora indicative of the *hamata–rarirrugulata* Biozone and graptolites of the *cucullus* Biozone; some trilobites have also been recorded. Graptolites of the *artus* Biozone and early *murchisoni* Biozone are recorded from higher in the succession at outcrop (Cooper et al., 2004; Rushton, 2006). The youngest part of the formation (*murchisoni* Biozone) is present within the Tarn Moor Tunnel (Wadge et al., 1969; Wadge, 1972).

Age

Late Arenig to Llanvirn.

Geographical limits

East part of the Skiddaw Inlier, and to the south of the Causey Pike Fault; also present in the Ullswater and Bampton inliers. The youngest part of the succession was recorded in the Tarn Moor Tunnel.

Maps

Keswick, Appleby.

Regional correlation

The correlated unit in the Cross Fell Inlier is the Kirkland Formation (Burgess and Wadge, 1974; Cooper and Molyneux, 1990).

4.3 RAVENGLASS INLIERS

Two small inliers of hornfelsed Skiddaw Group rocks are present west of the Eskdale Granite Pluton within the Central Fells Belt (Figure 1). It is not possible to recognise any stratigraphical divisions nor has it been possible to correlate these rocks with the main Skiddaw Group successions (Cooper et al., 2004).

4.4 SOUTHERN LAKE DISTRICT INLIERS

Division of the succession in the Black Combe Inlier, based on colour of the mudrocks, originated from the primary survey and was formalised as the Whicham Blue Slates, Townend Olive Slates and the Fellside Mudstones by Helm (1970). However, Bell (1992) and Johnson (1992) noted that the colour variation is a secondary effect and did not form a basis for either structural or stratigraphical interpretation. Thus, previous stratigraphical nomenclature in the inlier has been abandoned and one newly defined formation (Knott Hill Sandstone Formation) is recognised within an otherwise undivided Skiddaw Group (Figure 5; Johnson et al., 2001). Graptolite faunas from the Whicham valley indicate a biostratigraphical level within the *cucullus* Biozone (Rushton and Molyneux, 1989). No evidence was found for rocks of Llanvirn age.

In the two contiguous Furness inliers, the Skiddaw Group is poorly exposed and has not been divided. Graptolite faunas suggest the presence of the *cucullus* to *artus* biozones indicating that these rocks are a little younger than those in Black Combe (Cooper et al., 2004).

4.4.1 Knott Hill Formation (KHSA)

Name

The name is after Knott Hill in the north-east of the Black Combe Inlier by Johnson et al. (2001, p. 26). It is the only formal division of the Skiddaw Group succession recognised within the inlier.

Stratotype

Type area around Knott Hill [SD 1740 8720 to SD 1760 8740], 900 m north-west of Broadgate, near Hallthwaites, Cumbria.

Lithology

Sandstone, laminated and thin bedded at the base, but with bedding becoming less well developed upwards; locally the lithology is massive. There is some soft-sediment deformation.

Definition of lower boundary

There is a gradational passage with sandy laminae within the underlying silty mudstone of the undivided part of the Skiddaw Group, increasing in abundance and thickness over 10 to 15 m. The base of the Knott Hill Sandstone Formation is defined where sandstone becomes predominant.

Definition of upper boundary

Not seen as the upper contact is eroded beneath the unconformity with the Borrowdale Volcanic Group.

Thickness

Up to 300 m.

Genetic interpretation

Uncertain: Johnson et al. (2001) did not interpret the depositional mechanism or environment of these rocks.

Biostratigraphical characterisation

No palaeontological information exists for this formation.

Age

Possibly Arenig, but this is uncertain (Johnson et al., 2001; Cooper et al., 2004). It appears to be the youngest part of the Skiddaw Group in the Black Combe Inlier.

Geographical limits

Restricted to the Black Combe Inlier and to within 1 km of the summit of Knott Hill.

Maps

Black Combe (1:25 000); Ulverston.

4.5 CROSS FELL INLIER

Nicholson and Marr (1891) first divided Skiddaw Group strata in the inlier into an unnamed, oldest division in the north, the Ellergill Beds, and the youngest, Milburn Beds. Shotton (1935) added further biostratigraphical information, and applied the terms Ellergill and Milburn groups. The stratigraphy was revised completely during the resurvey of the inlier, with introduction of

the Murton and Kirkland formations (Burgess and Wadge, 1974; Burgess and Holliday, 1979; Arthurton and Wadge, 1981). Most recently, new structural and biostratigraphical information from the region led Cooper and Molyneux (1990) to update this scheme, introducing the Catterpallot Formation and correlating the succession with that in the Lake District Inlier. It is their scheme that is followed herein.

4.5.1 Catterpallot Formation

Name

This name was introduced and the formation defined by Cooper and Molyneux (1990) for the Skiddaw Group rocks in the north of the Cross Fell Inlier. Previously, these rocks had been included in the Murton Formation (Burgess and Wadge, 1974; Wadge, 1978; Arthurton and Wadge, 1981), though it was recognised that the rocks in the north were distinct lithologically from those that comprise the Murton Formation in the south. Cooper and Molyneux demonstrated that the Catterpallot Formation is the oldest division in the Cross Fell Inlier. A summary is given by Cooper et al. (2004, p. 60).

Stratotype

The type area is defined on Catterpallot Hill [NY 638 363] and adjacent streams of Dry Sike, Hungrigg Sike, Martins Sike and Melmerby Beck [NY 620 370].

Lithology

The formation comprises turbiditic siltstones interbedded with beds and sequences of lithic greywacke sandstone which constitute between 20 and 40 per cent of the succession. The sandstone is fine to medium grained in beds generally 5 to 150 cm thick, but exceptionally up to 5 m. A 4 m thick conglomerate is recorded in Melmerby Beck (Arthurton and Wadge, 1981).

Definition of lower boundary

The base is not exposed.

Definition of upper boundary

The contact with the younger Kirkland Mudstone Formation is faulted.

Thickness

At least 1000 m.

Biostratigraphical characterisation

Macrofossils have not been found, but the acritarch microflora indicate a latest Tremadoc age (Cooper and Molyneux, 1990).

Age

Latest Tremadoc.

Geographical limits

Restricted to the Cross Fell Inlier, to the north of the inferred eastward extension of the Causey Pike Fault: occurs on Catterpallot Hill [NY 638 363], and adjacent streams of Dry Sike [NY 630 370], Hungrigg Sike, Melmerby Beck and Martins Sike.

Regional correlation

Cooper and Molyneux (1990) considered these rocks to be comparable in age with the Watch Hill and Bitter Beck formations of the Lake District, but there is sufficient lithological distinction for the Catterpallot Formation to be regarded as a separate unit.

Maps

Not used on any currently published Geological Survey map. However, it is the outcrop of the Murton Siltstone Formation on the Penrith sheet that should be classified as Catterpallot Formation.

4.5.2 Murton Siltstone Formation (MUTN)

Name

The formation was designated by Burgess and Holliday (1979). Further details are given by Cooper and Molyneux (1990) and Cooper et al. (2004, p. 60).

Stratotype

The type area is defined as the north-south ridge on the west side of High Cup Gill [NY 7235 2365 to NY 7214 2422] and a short reference section is selected in Murton Beck [NY 7380 2235].

Lithology

Pale and dark grey siltstone with subordinate, interbedded pale grey sandstone, 0.5 to 5 cm thick. Many exposures show complex polyphase deformation with abundant sheared folds and shear planes suggesting soft-sediment slumping.

Definition of lower boundary

The base is not proved.

Definition of upper boundary

The upper contact with the younger Kirkland Mudstone Formation is faulted and the Murton Siltstone Formation is unconformably overlain to the east by Carboniferous rocks.

Thickness

At least several hundred metres, but true thickness is unknown.

Biostratigraphical characterisation

Graptolites are rare, but a single trilobite has been recorded (Fortey et al., 1989). Acritarchs were first recorded by Lister et al. (1969) and probably provide a proxy for the *cucullus* Graptolite Biozone (Cooper and Molyneux, 1990).

Age

Late Arenig (Cooper and Molyneux, 1990).

Geographical limits

Cross Fell Inlier, south of the inferred extension of the Causey Pike Fault.

Maps

Cross Fell (1:25 000); Penrith, Brough-under-Stainmore. The occurrence of the Murton Formation shown on Penrith should now be reclassified as Catterpallot Formation.

Regional correlation

The age and overall lithofacies of the Murton Siltstone Formation resembles the Buttermere Formation of the Central Fells Belt, but there are no records of the occurrence of major olistoliths (Cooper et al., 2004).

4.5.3 Kirkland Mudstone Formation (KDF)

Name

The Kirkland Formation was defined by Burgess and Wadge (1974), and further details were given by Burgess and Holliday (1979) and Arthurton and Wadge (1981). Later amendments were made by Cooper and Molyneux (1990), and further details are given by Cooper et al. (2004, p. 60).

Stratotype

A partial type section is defined in Milburn Beck, about 2 km east of Milburn, Cumbria [NY 6787 2922 to NY 6865 2992] and a reference section at Wythwaite Hole and Wythwaite Top, about 3 km north of Milburn, Cumbria [NY 6611 3278 to NY 6618 3269] (Arthurton and Wadge, 1981).

Lithology

Grey mudstone and siltstone with subordinate beds of brown weathered, pyritic mudstone and dark blue-grey calcareous mudstone. These strata are interbedded with many thick units up to 20 m of volcaniclastic rocks and are locally intruded by altered basalt and andesite sills, previously interpreted as lavas (Hughes and Kokelaar, 1993).

Definition of lower and upper boundaries

The formation is fault bound and neither the base nor top are proved.

Thickness

At least 1000 m.

Biostratigraphical characterisation

The abundant graptolite fauna is indicative of the *artus* Biozone (Cooper and Molyneux, 1990).

Age

Early Llanvirn.

Geographical limits

Cross Fell Inlier, Cumbria. The exposure of Skiddaw Group rocks at Cronkley Pencil Mill [NY 8485 2955] in the Teesdale Inlier has yielded a probable early Llanvirn biostratigraphical age (Johnson, 1961; Lister and Holliday, 1970) suggesting a correlation with the Kirkland Formation. Thus, this unit may be present more extensively beneath Carboniferous rocks of the Alston Block.

Maps

Cross Fell, Middleton-in-Teesdale (1:25 000); Penrith, Alston, Appleby, Brough-under-Stainmore.

Regional correlation

The Kirkland Formation resembles the Tarn Moor Formation of the Central Fells Belt, though it is biostratigraphically more restricted (Cooper et al., 2004).

4.6 TEESDALE INLIER

Exposure here is poor, but the lithofacies and the graptolite and acritarch fauna recovered from these rocks invites correlation with the Kirkland Mudstone Formation of the Cross Fell Inlier (Johnson, 1961; Lister and Holliday, 1970; Cooper et al., 2004).

5 Manx Group

The lithostratigraphy of the Manx Group follows that erected by Chadwick et al. (2001), which was developed from Woodcock et al. (1999). The biostratigraphy is based on the acritarch scheme erected by Molyneux (1979, 1999, 2001) in conjunction with the acritarch and graptolite studies from the Skiddaw Group by Cooper et al. (2004). A simplified geological map is given in Figure 7 and correlation with the Skiddaw Group in Figure 8. The units are defined below in three successions reflecting their structural disposition across the island: north-west, west/central and south-east.

5.1 NORTH-WEST AND NORTH-WEST COAST

5.1.1 Glen Dhoo Mudstone Formation (GLDH)

Name

This formation was a formalisation by Chadwick et al. (2001) of Simpson's (1963) Glen Dhoo Flags. The Glen Dhoo Mudstone Formation was partly recognised by Woodcock et al. (1999), and Quirk and Burnett (1999) as the Glen Dhoo and Glion Cam units. There is lithological similarity and biostratigraphical overlap with the Lonan Sandstone Formation and these units may be equivalent (Chadwick et al., 2001, p. 19–20). The formation is named after the location of its type section.

Stratotype

The type area is defined around Glen Dhoo [SC 3498 8995], 3 km east of Kirk Michael, Isle of Man (Chadwick et al., 2001).

Lithology

Pale grey mudstone with a variable proportion of siltstone laminae and sandstone in thin beds; locally sandstone predominates in thin- to thick-bedded units; massive siltstone occurs locally. At two localities, the formation includes andesitic tuff and breccia.

Boundaries

Both lower and upper boundaries are faulted.

Thickness

About 300 m.

Biostratigraphical characterisation

Molyneux (1999) referred the acritarch assemblages from this formation to the upper part of the *messaoudensis–trifidum* Biozone or the *trifidum–bohemicum* Biozone. They suggest correlation with the upper part of the *murrayi*, the *phyllograptoides* or lower part of the *varicosus* Graptolite biozones (Chadwick et al., 2001).

Age

Latest Tremadoc to early Arenig.

Geographical limits

North-west Isle of Man.

5.1.2 Lady Port Mudstone Formation (LPT)

Name

Defined by Woodcock et al. (1999) to replace the Lady Port Banded Group and Ballanayre Slump Breccia of Simpson (1963) and named after Lady Port bay. Detailed description has been provided by Woodcock and Morris (1999). On the 1:50 000-scale geological map the formation is spelt 'Ladyport', but in common with names within the Skiddaw Group, 'Lady Port', as on current topographical maps, is preferred (Chadwick et al., 2001, p. 29–30).

Stratotype

Woodcock et al. (1999) defined the type area as the coastal section from Will's Strand [SC 2696 8609], to about 200 m south-west of Glen Moar [SC 3036 8908], north-east of Peel, Isle of Man.

Lithology

Heterogeneous, medium-grey to black mudstone, with thin to thick siltstone laminae and punctuated in places by thin- or very thin-bedded quartzose sandstone. Thin- to medium-bedded greywacke occurs in places in units fining upwards from fine- or very fine-grained sandstone to mudstone. Pebbly mudstone (debrite) well developed locally, containing rafts up to 50 m locally. The formation is interpreted as the product of deep marine sedimentation that was affected by episodes of slumping and olistostrome formation.

Definition of lower boundary

The base is not proved and the formation is faulted against the Glen Dhoo Formation.

Definition of upper boundary

Not proved.

Thickness

About 250 m.

Genetic interpretation

Deposition was in a deep marine, mudstone-dominant basin subjected to repeated episodes of slumping and debris flows (Woodcock and Morris, 1999).

Biostratigraphical characterisation

Molyneux (1979, 1999) assigned the formation to the *hamata–rarirrugulata* acritarch Biozone.

Age

Late Arenig.

Geographical limits

West coast of the Isle of Man, to south-west and north-east of Lady Port.

5.2 WEST/CENTRAL AREA

5.2.1 Barrule Mudstone Formation (BRUL)

Name

Defined by Chadwick et al. (2001, p. 26–27) to include the Barrule Slates of Lamplugh (1903), except for the outcrop in the south-west that was separated out by Woodcock et al. (1999) as the Glen Rushen Formation. Earlier, Simpson (1963) had retained Lamplugh's term except in the

north where he recognised a unit referred to as the Slieau Managh Slates. The Slieau Managh Slates were retained by Quirk and Burnett (1999), but remained outside the area described by Woodcock et al. Chadwick et al. included the Slieau Managh Slates within the Barrule Formation.

Stratotype

Type area at South Barrule [SC 2580 7590], Isle of Man (Woodcock et al., 1999).

Lithology

Dark grey to black, homogeneous, apparently massive mudstone, which in clean sections has a diffuse parallel lamination.

Definition of lower boundary

Not proved, but the formation is faulted against the Maughold and Injebreck mudstone formations in thrust-repeated slices.

Definition of upper boundary

The top is marked by the incoming of siltstone and sandstone at the base of the conformably overlying Injebreck Mudstone Formation.

Thickness

Up to 900 m but, as the base is not seen and there may be internal repetition through folding, the full thickness remains uncertain.

Genetic interpretation

These rocks are interpreted to have been hemipelagic mud deposited under anoxic conditions (Chadwick et al., 2001).

Biostratigraphical characterisation

The sparse, low-diversity acritarch flora suggests an age not older than early Arenig (Molyneux, 2001).

Age

Arenig.

Geographical limits

The formation crops out across the spine of the Isle of Man from north-east of Burroo Mooar on the west coast to Port Lewaigue, near Ramsey.

5.2.2 Injebreck Mudstone Formation (IBK)

Name

The Injebreck Mudstone Formation was defined by Woodcock et al. (1999), following the use of the term Injebreck Banded Group by Simpson (1963). Lamplugh (1903) had not separated these rocks within his Manx Slate Series. The formation also includes the Sulby Slump Breccia of Simpson (1963).

Stratotype

Partial type sections defined by Woodcock et al. (1999) about 3 km north-north-east of Fleshwick on the west coast of the Isle of Man, from Lag ny Keeilley to Con Shellagh [SC 2158 7453 to SC 2165 7495] and from Da Leura to Gob yn Ushtey [SC 2175 7530 to SC 2152 7565].

Lithology

Dark grey mudstone with pale siltstone laminae, and quartz arenite sandstone as thin to medium beds locally forming units up to several tens of metres thick. Pebbly mudstone (debrite) extensive in north, more local in the south.

Definition of lower boundary

Conformably overlying the Barrule Mudstone Formation, with the base marked by incoming of siltstone and sandstone.

Definition of upper boundary

The upper contact is transitional, taken at the loss of the sandstone component into the conformably overlying mudstone succession of the Glen Rushen Mudstone Formation.

Thickness

About 500 m.

Genetic interpretation

Interpreted as hemipelagic fallout with deposition from sporadic low-concentration turbidity currents (Chadwick et al., 2001, p. 27–28).

Biostratigraphical characterisation

The sparse low-diversity acritarch flora obtained is insufficient to date the rocks with certainty.

Age

Arenig.

Geographical limits

Across the spine of the Isle of Man from Ramsey to the west coast.

5.2.3 Glen Rushan Mudstone Formation (GLRN)

Name

Defined by Woodcock et al. (1999) for the north-western outcrop of the Barrule Slates of Lamplugh (1903) and Simpson (1963).

Stratotype

Woodcock et al. (1999) defined the type section at Glen Rushen slate quarries [SC 2445 7845], and a reference section along the coast at Fheustal [SC 2173 7654].

Lithology

Dark grey to black mudstone, with pale siltstone laminae.

Definition of lower boundary

Conformably overlies the Injebreck Mudstone Formation from which it is distinguished by the absence of the sandstone component.

Definition of upper boundary

Taken at the change to a mudstone–sandstone facies containing manganiferous ironstone beds of the conformably overlying Creggan Moar Mudstone Formation.

Thickness

250 to 500 m.

Genetic interpretation

Woodcock et al. (1999) interpreted the formation as an anoxic hemipelagic facies with episodic low-concentration turbidity flows.

Biostratigraphical characterisation

The low-diversity acritarch flora from most of the formation indicates an Arenig age. However, diagnostic floras from the uppermost part of the formation or from just within the overlying Creggan Moar Mudstone Formation may indicate that the base of the mid Arenig *pseudoornatum* Biozone occurs at this level (Chadwick et al., 2001, p. 28).

Age

Arenig.

Geographical limits

South-west Isle of Man.

5.2.4 Creggan Moar Mudstone Formation (CRMR)

Name

Introduced and defined by Woodcock et al. (1999) for the mudstone sequence containing manganiferous ironstone beds. Previously these had been included within Lamplugh's (1903) undivided Manx Slate Series and later in Simpson's (1963) Maughold Banded Group. A full description is provided by Kennan and Morris (1999). The name is from the hamlet of Creggan Moar [SC 2195 7711]. Note that the spelling is 'Moar' in Chadwick et al. (2001), but 'Mooar' on the Isle of Man 1:50 000-scale geological map. The current spelling in the Ordnance Survey's gazetteer of place names (Moar) is preferred.

Stratotype

Woodcock et al. (1999) defined the type section at Gob ny Gamera [SC 2170 7650] and a reference section along the coast from Fheustal to Niarbyl [SC 2173 7654 to SC 2118 7758], south of Niarbyl Bay on the west coast of the Isle of Man.

Lithology

Dark grey mudstone, with laminae of pale siltstone and thin- to medium-bedded quartz arenite sandstone; contains distinctive laminae of manganiferous ironstone.

Definition of lower boundary

The base of the Creggan Moar Mudstone Formation is conformable on the Glen Rushen Mudstone Formation, with the base taken at the incoming of sandstone and manganiferous beds.

Definition of upper boundary

Not proved as the formation is faulted against the Niarbyl Formation (Dalby Group).

Thickness

About 500 m.

Genetic interpretation

The formation was deposited from low-concentration turbidity flows and as chemical precipitates into oxygenated bottom water conditions (Chadwick et al., 2001, p. 28–29).

Biostratigraphical characterisation

The mid Arenig *pseudoornatum* acritarch Biozone is indicated from samples obtained from near the base of the formation. However, samples from Creggan Moar have yielded taxa tentatively taken as indicative of the late Arenig *hamata–rarirrugulata* Biozone (Chadwick et al., 2001).

Age

Arenig.

Geographical limits

Western Isle of Man inland from Peel.

5.3 SOUTH-EAST AREA

5.3.1 Lonan Sandstone Formation (LNN)

Name

The Lonan Sandstone Formation was formalised by Chadwick et al. (2001, p. 21–24) to include much of the sequence of the Manx Group in the south-east of the island. The formation is named after the eponymous district on the island. Woodcock et al. (1999) divided the coastal outcrops of the Lonan Flags of Lamplugh (1903) into four formations, but this subdivision could not be sustained inland by Chadwick et al., though distinct units seen along the coast were retained as members.

Formal subdivisions

Three units have been defined: Keristal, Santon and Ny Garvain members. The last two may be equivalent.

Stratotype

The type area is defined as the coastal section in Laxey Bay [SC 4400 8344 to SC 4476 8313], on the east coast of the Isle of Man.

Lithology

Mainly of thin and very thin-bedded or thickly laminated, fine-grained sandstone (lithic wacke) or siltstone and mudstone couplets. The sandstone proportion is 25 to 80 per cent. The formation also contains units dominated by thin- and medium-bedded sandstone, three persistent and well exposed units of which have been given status as the Keristal, Santon and Ny Garvain members.

Definition of lower boundary

The base is not proved.

Definition of upper boundary

The top is a transition into the dominantly quartz arenite-bearing succession of the Creg Agneash Sandstone Formation in the north-east of the island and into the Mull Hill Sandstone Formation in the south.

Thickness

At least 2500 m.

Genetic interpretation

Chadwick et al. (2001) indicated that these rocks were the products of low-concentration turbidity currents, deposited in an oxygenated, deep marine environment.

Biostratigraphical characterisation

Acritarch floras obtained by Molyneux (2001) from below the Santon Sandstone Member are indicative of a Tremadoc age, whereas those from the Santon Sandstone Member are considered to correlate with the *trifidum–bohemicum* or upper part of the *messaoudensis–trifidum* Biozone (Molyneux, 1999) and so may be Tremadoc or Arenig. Poorly preserved graptolites have also been obtained from the Santon Sandstone Member and broadly indicate an Arenig age (Rushton, 1993).

Age

Tremadoc to Arenig.

Geographical limits

South-east side of the Isle of Man, from the Calf of Man in the south-west almost to Maughold Head on the south side of Ramsey Bay.

Regional correlation

Biostratigraphy suggests that the Lonan and Glen Dhoo formations may be laterally equivalent.

5.3.1.1 KERISTAL SANDSTONE MEMBER (KERI)

Name

The member was introduced by Woodcock et al. (1999), and named after its exposure in Keristal Bay, north-east of Port Soldrick. Further description is given by Chadwick et al. (2001, p. 23).

Stratotype

Type section is on the west side of Keristal Bay [SC 3505 7296], Isle of Man.

Lithology

Medium to thick-bedded, fine-grained quartz arenite or quartz wacke sandstone in coarsening and fining upwards units. Compared with other Lonan Formation sandstone units this member is composed of quartz-rich sand.

Definition of lower boundary

The base is taken at the base of the first quartz-rich sandstone within the Lonan Sandstone Formation.

Definition of upper boundary

Taken at the return to lithic wacke sandstone beds typical of the Lonan Formation.

Thickness

5–10 m.

Age

Probably Tremadoc or earliest Arenig based on acritarch assemblages from the underlying Lonan Sandstone Formation and early Arenig microfloras from the overlying Santon Sandstone Member (Chadwick et al., 2001, p. 23).

Geographical limits

South-east coast of Isle of Man, from Port Soldrick north-east to Garwick Bay, a distance of about 15 km. It may be also present further north-east around Port Cornaa [SC 4736 8786] if the Santon and Ny Garvain members prove to be correlatives (Chadwick et al., 2001).

5.3.1.2 SANTON SANDSTONE MEMBER (SNTN)

Name

The Santon Formation of Woodcock et al. (1999) and Woodcock and Barnes (1999) was reduced to member status by Chadwick et al. (2001, p. 24). The name is after the occurrence of these rocks at Santon Head.

Stratotype

A partial type section was defined by Woodcock et al. (1999) on the coast from Baltic Rock to Santon Head [SC 3290 7031 to SC 3328 7022], Isle of Man.

Lithology

Light grey or light greenish grey medium- or thick-bedded wacke, intercalated with a thin-bedded facies more typical of the main part of the Lonan Sandstone Formation. The sandstone beds grade from fine or very fine grained into the mudstone. In places the sandstone becomes quartz arenite. An unusually thick-bedded, coarse-grained sandstone unit up to 50 m thick is present at Purt Veg [SC3255 7037].

Definition of lower boundary

Taken at the base of the lowest unit of medium- or thick-bedded greywacke within the Lonan Formation.

Definition of upper boundary

Not seen.

Thickness

At least 600 m.

Age

Early Arenig based on the biostratigraphical characterisation summarised in Section 5.3.1.

Geographical limits

South-east coastal area of the Isle of Man, from Port Solderick to Garwick Bay, within the core of the Douglas Syncline.

5.3.1.3 NY GARVAIN SANDSTONE MEMBER (NGN)

Name

The term Ny Garvain Formation was introduced by Woodcock et al. (1999) for the north-eastern extent of what is now regarded as the Lonan Sandstone Formation. During the resurvey Chadwick et al. (2001, p. 24) restricted the definition of the Ny Garvain Formation to a package of sandstone present south from the headland of Gob ny Garvain and reduced its status to member of the Lonan Formation. The Ny Garvain Sandstone Member may be equivalent to the Santon Sandstone Member farther south-west (Chadwick et al., 2001).

Stratotype

The partial type section is along the coast from Port Cornaa to Traie Farkan [SC 4738 8787 to SC 4958 9128], Isle of Man.

Lithology

Units of medium- to thick-bedded, fine- to medium-grained sandstone with thin muddy partings interspersed with units of thin-bedded sandstone and mudstone couplets. Thicker sandstone beds are massive or weakly graded in the lower part. At the base, locally, is a unit comprising thick to very thick beds of quartz arenite, similar to the Keristal Sandstone Member farther south.

Definition of lower boundary

Taken at the base of the distinctive quartz arenite where this is present; elsewhere it is taken at the incoming of medium and thick beds of sandstone within the generally thin-bedded to laminated main part of the Lonan Sandstone Formation.

Definition of upper boundary

The upper boundary is not seen, though an upward-thinning sequence along the south side of Port Mooar, west of Gob ny Garvain may represent its transition back into undivided Lonan Sandstone Formation.

Thickness

At least 250 m.

Age

Probably late Tremadoc or Arenig based on its stratigraphical position within the Lonan Sandstone Formation.

Geographical limits

East coast of the Isle of Man, from near Dhoon north to Gob ny Garvain.

5.3.2 Creg Agneash Sandstone Formation (CGA)

Name

Introduced by Woodcock et al. (1999) and named from Creg Agneash [SC 4295 8705]. It equates to the north-eastern outcrop of Lamplugh's (1903) Agneash Grits. Simpson (1963) included these rocks as part of his Maughold Banded Group. In the south-west of the island the Mull Hill Sandstone Formation may be equivalent.

Stratotype

The type section is Maughold Head [SC 4986 9142], Isle of Man (Woodcock et al., 1999).

Lithology

White quartz arenite, thin or medium bedded, but locally thick or very thick bedded. In the lower part sandstone is interbedded with laminated siltstone and mudstone, but this passes upwards into thin persistent interbeds of dark grey silty mudstone. The sandstone is massive to weakly graded and slump folding is widely developed. Deposition was from medium concentration turbidity currents (Woodcock et al., 1999). Further description is given by Chadwick et al. (2001, p. 24–25).

Definition of lower boundary

The base is transitional from the underlying Lonan Sandstone Formation with quartz arenite beds becoming increasingly abundant over an interval of several tens of metres within mudstone of Lonan Sandstone Formation type; the base of the Creg Agneash Formation is taken where quartz arenite becomes the dominant lithology.

Definition of upper boundary

Transitional into the overlying Maughold Formation; sandstone beds progressively decrease in number and top is taken at the abrupt change to laminated silty mudstone.

Thickness

At least 180 m and possibly up to 750 m though there may be some repetition by folding.

Biostratigraphical characterisation

A sparse, low-diversity acritarch flora is not diagnostic and the age is extrapolated from the overlying Maughold Mudstone and underlying Lonan Sandstone formations.

Age

Probably Arenig based on the ages of adjacent units.

Geographical limits

Eastern Isle of Man, south-west from Maughold Head, to inland from Douglas.

5.3.3 Mull Hill Sandstone Formation (MHL)

Name

The formation was introduced by Woodcock et al. (1999) and named after Mull Hill. Lamplugh (1903) informally referred to these rocks as the Mull Hill Grits, though he ultimately grouped these with other similar lithofacies as the Agneash Grits. Simpson (1963) included the Mull Hill Formation rocks with his Maughold Banded Group.

Stratotype

The type section is along the west side of Chapel Bay, Port St Mary [SC 2100 6800], Isle of Man.

Lithology

Light grey to white, medium- to very thick-bedded quartz arenite, in beds that typically grade upwards from medium- to very fine-grained sand or silt; some units are capped by mudstone laminae.

Definition of lower boundary

The base is a gradation over about 25 m from the generally fine-grained lithofacies of the underlying Lonan Sandstone Formation into the Mull Hill Sandstone Formation.

Definition of upper boundary

The top is not seen in the Cregneash peninsula as the rocks form the cores of synclines. In the Silverdale outcrops the top of the Mull Hill Sandstone Formation is concealed beneath the unconformity at the base of Carboniferous strata.

Thickness

40 to 400 m.

Genetic interpretation

Deposition from medium- and high-concentration turbidity currents is inferred (Chadwick et al., 2001, p. 25).

Biostratigraphical characterisation

A very sparse, low-diversity acritarch flora is not diagnostic. The age is inferred.

Age

Arenig.

Geographical limits

Restricted to the Cregneash peninsula and Silverdale, north of Castletown, south-west Isle of Man.

5.3.4 Maughold Mudstone Formation (MGD)

Name

Defined by Woodcock et al. (1999) following Simpson's Maughold Banded Group. These rocks were originally included within the undivided Manx Slate Series by Lamplugh (1903). The name is after the village of Maughold [SC 4920 9170].

Stratotype

Type section on the coast west of Port Lewaigue [SC 4682 9304 to SC 4630 9328], near Ramsey, Isle of Man (Woodcock et al., 1999).

Lithology

Dark grey mudstone, typically with millimetre-scale pinstripe lamination, interbedded with a variable proportion of laminae or very thin beds of pale grey siltstone; locally significant interbeds of quartz arenite sandstone. The mudstone is commonly bioturbated. A pebbly mudstone facies comprises up to 65 per cent of the formation in the south-west; the pebbles are of mudstone siltstone and fine-grained sandstone and rare fine-grained igneous rock set in a mudstone matrix.

Definition of lower boundary

Gradational contact with the underlying Creg Agneash Sandstone Formation, with the base of the Maughold Mudstone Formation taken at the abrupt change to laminated silty mudstone. In the south-west of the island where the Maughold Mudstone Formation is underlain by the Mull Hill Sandstone Formation, a similar relationship is presumed though the contact is faulted. In the

centre of the island, west of Douglas where the intervening sandstone units of the Creg Agneash and Mull Hill sandstone formations are absent, the Maughold Mudstone Formation succeeds the Lonan Sandstone Formation; the contact is difficult to define (Chadwick et al., 2001, p. 25–26).

Definition of upper boundary

The north-west contact of the Maughold Mudstone Formation is faulted, but an original stratigraphical contact with the Barrule Formation was inferred by Chadwick et al. (2001).

Thickness

500 to 600 m, but uncertain because structure is poorly known.

Genetic interpretation

The mudstone is thought to represent hemipelagic sedimentation and deposition from low-concentration turbidity currents in a deep-marine environment that was periodically oxygenated (Woodcock et al. 1999). By contrast the sandstone units resulted from medium to high-concentration turbidity flows. The pebbly mudstone facies resulted from resedimentation due to slope instability.

Biostratigraphical characterisation

The acritarch flora is sparse and low diversity, and nondiagnostic.

Age

Arenig.

Geographical limits

Central Isle of Man, from Maughold Head south-west to Port Erin.

6 Dent Group

The Dent Group is described below in relation to five areas: Northern Lake District, Cross Fell Inlier, Cautley and Dent inliers, Southern Lake District and Craven inliers (Figure 9). The adopted lithostratigraphical scheme is mainly that of Kneller et al. (1994), with some amendments. The most complete succession of Upper Ordovician strata in northern England is seen in the Cautley and Dent inliers (Ingham, 1966). Though the Dent Group strata are extensively faulted in the Cross Fell Inlier, lithofacies and their faunal assemblages from well exposed stream sections have been pieced together to provide substantial additional detail of the older part of the succession. The numerous exposures along the southern margin of the Borrowdale Volcanic Group outcrop from Furness to Shap, give extensive evidence of a dynamic nearshore marine environment. The nationally significant stratigraphical sections which have been designated as Geological Conservation Review sites are described by Owen and Rushton (1999).

6.1 NORTHERN LAKE DISTRICT

The Dent Group in this area is represented by a single unit, the Drygill Formation which crops out in a fault-bound inlier on the north flank of Carrock Fell, in the northern Lake District (Figure 1).

6.1.1 Drygill Mudstone Formation (DRSH)

Name

This is a formalisation of the term Drygill Shales, established by Nicholson and Marr (1887) and described further by Elles and Wood (1895), Dean (1963) and Eastwood et al. (1968). Though similar in lithofacies to the Dufton Mudstone Formation in the Cross Fell Inlier, and partly overlapping in age, the Drygill Mudstone Formation contains the oldest post-Borrowdale/Eycott Volcanic Group strata in northern England.

Stratotype

A partial type section is in Drygill Beck and on the surrounding fell side, north side of Carrock Fell, Cumbria [NY 3185 3462 to NY 3260 3441].

Lithology

Fissile, thinly bedded and laminated, grey to black calcareous mudstone and siltstone, with an abundant shelly fauna. Locally, pervasively bleached adjacent to intrusions.

Definition of lower and upper boundaries

Neither the base nor top of the formation are proved because the outcrops are either faulted or in contact with intrusive igneous rocks.

Thickness

About 200 m seen, but full thickness unknown.

Genetic interpretation

The depositional environment was on an open shelf with conditions suitable for the abundant marine fauna.

Biostratigraphical characterisation

The formation contains a Longvillian fauna of trilobites and brachiopods (Dean, 1963).

Age

Caradoc: Burrellian (Longvillian).

Geographical limits

Confined within a small outlier on the north side of Carrock Fell in the northern Lake District.

Map

Cockermouth.

6.2 CROSS FELL INLIER

The Upper Ordovician strata in the Cross Fell Inlier comprise four formations: Dufton Mudstone, Swindale Limestone, Keisley Limestone and Ash Gill Mudstone. The most recent descriptions of these strata are as parts of the Coniston Limestone Group (Burgess and Wadge, 1974; Burgess and Holliday, 1979; Arthurton and Wadge, 1981), though Kneller et al. (1994) brought this group under the aegis of the Dent Group. Early descriptions of the Cross Fell strata are by Harkness and Nicholson (1877), and Nicholson and Marr (1891). The development of stratigraphical knowledge in the area is summarised by Owen and Rushton (1999), who stressed the importance of the succession here in the understanding of the region during Late Ordovician times. Pus Gill [NY 696 256 to NY 704 262] is the historical type section for the Pusgillian Stage (Bancroft, 1945).

6.2.1 Dufton Mudstone Formation (DNSH)

Name

This formalises the long-established Dufton Shales (e.g. Harkness and Nicholson, 1877; Shotton, 1935; Dean, 1959; Burgess and Holliday, 1979). Ingham and McNamara (1978) formalised this to Dufton Shale Formation, and this has been used since by, for example, Kneller et al. (1994), Owen and Rushton (1999), and Fortey et al. (2000). However, mudstone is preferred to shale here as the lithological epithet.

Formal subdivisions

A number of divisions have been used but the only one formalised herein, is the Billy's Beck Siltstone Member (Kneller et al., 1994; Fortey et al., 2000) in the uppermost part of the formation. These strata are the Diacalymene Beds of Dean (1959). The basal volcaniclastic strata of the formation that overlie the Borrowdale Volcanic Group were termed the Corona Series by Nicholson and Marr (1891) and Corona Beds by Dean (1959) after the presence of the brachiopod *Trematis corona*. Dean defined this unit to include all Lower Longvillian strata present. Dean (1959) proposed the name Melmerby Beds for the faunally distinct lower Longvillian strata in the Melmerby road section which are not of a volcaniclastic character. Neither the Corona Beds nor the Melmerby Beds were considered as mappable units by Burgess and Holliday (1979) who preferred to use the term corona facies and it is this usage that is retained herein.

Stratotype

The most complete succession of the Dufton Mudstone Formation is in Swindale Beck (Knock Gill) [NY 6885 2776 to 6878 2742], and this is designated as the type section (Dean, 1959). Further important reference sections are alongside the Melmerby Road [NY 623 383 to NY 623 385] in Pus Gill [NY 696 256 to NY 704 262] and in Harthwaite Sike [NY 702 247 to NY 708

248]. Descriptions of these sections are by Arthurton and Wadge (1981), Burgess and Holliday (1979), and Owen and Rushton (1999). Owen and Rushton regarded Swindale Beck as the most important stratigraphical section in the Cross Fell Inlier.

Lithology

The Dufton Mudstone Formation is composed of dark grey, partly calcareous, siltstone and mudstone, with thin beds, lenses or nodules of silty limestone, and has a rich shelly fauna (Burgess and Holliday, 1979; Arthurton and Wadge, 1981). Poorly fossiliferous sandstone and siltstone incorporating abundant debris from the Borrowdale Volcanic Group that occur at the base of the formation are referred to as the corona facies after the presence of the brachiopod *Trematis corona*. A quartz-rich sandy siltstone facies in the highest part of the formation is defined as the Billy's Beck Siltstone Member.

Definition of lower boundary

Taken at the base of sparsely fossiliferous sandstone and siltstone that overlies volcaniclastic rocks of the Harthwaite Formation (Borrowdale Volcanic Group).

Definition of upper boundary

The Dufton Mudstone Formation is overlain by limestone of the Swindale Limestone or Keisley Limestone formations, or where these are absent, the Ash Gill Mudstone Formation. The upper boundary is an unconformity (Owen and Rushton, 1999).

Thickness

About 400 m.

Genetic interpretation

The basal corona facies represents deposition in shallow water, inhabited at first by a lingulid community with sporadic infaunal and epifaunal mollusca. The higher parts of the succession represent a deepening offshore marine environment with deposition of fine clastic material and carbonate mud. The Billy's Beck Siltstone Member saw in influx of quartz-rich sediment.

Biostratigraphical characterisation

Shelly faunas including brachiopods, trilobites and ostracods are locally abundant. These indicate that the basal part of the formation is Longvillian. They also indicate that the uppermost strata beneath the unconformity range from Pusgillian to early Cautleyan in age; all of the intervening substages of the Caradoc are represented within the various fault-bound outcrops, making the formation crucial to understanding the Late Ordovician history of northern England (Owen and Rushton, 1999).

Age

Caradoc: Burrellian (Longvillian) to Ashgill (early Cautleyan).

Geographical limits

Restricted to the Cross Fell Inlier.

Maps

Cross Fell (1:25 000); Penrith, Appleby, Brough-under-Stainmore.

Regional correlation

In part possibly equivalent to the Drygill Formation in the northern Lake District. There are lithological similarities with the Cautley Mudstone Formation of the Cautley and Dent inliers, with which the Dufton Mudstone Formation overlaps biostratigraphically.

6.2.1.1 BILLY'S BECK SILTSTONE MEMBER

Name

Kneller et al. (1994), and Fortey et al. (2000) formalised Dean's (1959) Diacalymene Beds as the Billy's Beck Member. It occurs in the highest part of the formation.

Stratotype

The type section is near the head of Billy's Beck [NY 708 253 to NY712 256], near Dufton.

Lithology

The strata comprise a quartz-rich sandy siltstone facies.

Definition of lower boundary

The base is taken at the change to quartz-rich sandy siltstone from calcareous siltstone of the main part of the Dufton Formation.

Definition of upper boundary

The top is not seen, but probably unconformably overlain by the Swindale Limestone Formation.

Thickness

No thickness is given by Dean (1959), and Burgess and Holliday (1979) state that the member is only a few metres thick.

Age

Ashgill (late Pusgillian to early Cautleyan).

Geographical limit

Restricted to the Cross Fell Inlier.

6.2.2 Swindale Limestone Formation (SWL)

Name

This term is a formalisation of Dean's (1959) Swindale Limestone, the rocks of which were formerly considered as equivalent to the Staurocephalus Limestone of earlier authors. Burgess and Wadge (1974), and Burgess and Holliday (1979) had included the Swindale Limestone as a lower member of their Swindale Shales. However, Bassett et al. (1992) considered the 'shales' overlying the limestone to be the direct equivalent of the Ash Gill Mudstone Formation of the southern Lake District. Kneller et al. (1994) gave formational status to the limestone in the text of their paper and on their figure 5, but followed Burgess and Holliday in their appendix of retained names. Owen and Rushton adopted the scheme after Bassett et al. and this is followed herein.

Stratotype

The type section in Swindale Beck, Cross Fell Inlier, Cumbria [NY 688 275 to NY 689 278] and the reference section alongside the Melmerby road (A686, Penrith to Alston), Cumbria [NY 623 383 to NY 623 385] are described by Owen and Rushton (1999).

Lithology

Grey nodular limestone with intercalations of pale grey mudstone with limestone nodules.

Definition of lower boundary

Taken at the base of limestone unconformably overlying mudstone of the Dufton Mudstone Formation. Faunal evidence demonstrates erosion to deeper levels to the north with the age of mudstone subjacent to the unconformity cutting down from lower Cautleyan to Pusgillian in a distance of 3 km (Owen and Rushton, 1999).

Definition of upper boundary

Taken at the base of mudstone belonging to the unconformably overlying Ash Gill Mudstone Formation.

Thickness

About 19 m.

Biostratigraphical characterisation

An abundant shelly fauna, particularly of brachiopods and trilobites, is reported from decalcified limestone beds and interbedded mudstone. A mid Rawtheyan age was suggested by some authors (e.g. Ingham, 1966), though Price (1981) later identified further taxa that indicate an age probably at about the Cautleyan–Rawtheyan boundary.

Age

Ashgill.

Geographical limits

Restricted to Cross Fell Inlier, Cumbria

Maps

Cross Fell (1:25 000); Penrith, Appleby, Brough-under-Stainmore.

Regional correlation

The age reported in Kneller et al. (1994) and Owen and Rushton (1999) suggests that the Swindale Limestone Formation correlates with the Broughton Moor Limestone Formation of the southern Lake District.

6.2.3 Keisley Limestone Formation (KYL)

Name

The Keisley Limestone was referred to first by Buckland (1817), and described in detail by Burgess and Holliday (1979). Owen and Rushton (1999) have summarised the large number of investigations on these rocks. Though stating that the Limestone has implied formational status, Kneller et al. (1994) included it only as a member in the appendix listing the retained names, presumably of their Swindale Shale Formation. The Keisley Limestone is here accorded formation status following the reassignment of the Swindale Shales to the Ash Gill Mudstone Formation and elevation of the Swindale Limestone to formational status.

Stratotype

A partial type section is designated in Keisley Quarry [NY 714 238], about 300 m east of Keisley, Cumbria (Owen and Rushton, 1999).

Lithology

Dark grey nodular limestone with siltstone partings, overlain by massive, thick beds of grey bioclastic limestone which are locally dolomitised; probably the lowest part seen comprises dark grey siltstone with thin impure limestone beds. A thin unit of synsedimentary breccia and siltstone occurs at the top of formation.

Definition of lower boundary

The formation is seen only in the core of a fault-bound anticline; the base is not proved.

Definition of upper boundary

Taken at the conformable base of black mudstones forming the overlying Silurian Skelgill Mudstone Formation.

Thickness

At least 50 m; full thickness is not known.

Genetic interpretation

Owen and Rushton (1999) described this as one of only a few examples of an Ordovician carbonate mudmound in the British Isles, and perhaps the best such in England.

Biostratigraphical characterisation

The formation is richly fossiliferous locally; however, the shelly fauna is distinctly facies controlled, with an assemblage that is difficult to correlate with the typical Ashgill taxa (Owen and Rushton, 1999). Wright (1985) confirmed an Hirnantian age for the upper part, though the age of the lower part is less well established. Burgess and Holliday (1979) and Fortey et al. (2000) show an age extending from late Cautleyan to Hirnantian, whereas Owen and Rushton (1999) and Kneller et al. (1994) showed a restricted range from late Rawtheyan to Hirnantian.

Age

Ashgill.

Geographical limits

Only seen in the Keisley area, Cross Fell Inlier, Cumbria.

Maps

Cross Fell (1:25 000); Brough-under-Stainmore.

Regional correlation

If the extended age range for the formation is correct then the lower part is correlated with the Swindale Limestone Formation, as inferred by Burgess and Holliday (1979), whilst the upper part of the formation is equivalent in age to the Ashgill Formation.

6.2.4 Ash Gill Mudstone Formation

See the Southern Lake District section for the definition of the formation (Section 6.4.5). In the Cross Fell Inlier, the formation was formerly referred to as the Swindale Shales (Burgess and Holliday, 1979), but following Bassett et al. (1992) these rocks are considered to belong to the Ash Gill Mudstone Formation.

6.3 INLIERS OF THE CAUTLEY AND DENT AREA

Dent Group rocks are exposed in the Murthwaite, Taythes and Westerdale inliers in the Cautley and Dent area. The first detailed description of the Upper Ordovician succession there was by Dakyns et al. (1891). Later, Marr (1913) revised the stratigraphy. The division into Cautley Mudstone Formation and the overlying Ash Gill Mudstone Formation adopted by Kneller et al. (1994) and by Rickards and Woodcock (2005) stems from the work of Ingham (1966), who also provided a full summary of previous work in this area.

6.3.1 Cautley Mudstone Formation (CMU)

Name

The Cautley Mudstones were defined by Ingham (1966) and given formational status by Ingham and McNamara (1978).

Formal subdivisions

Two distinctive units are designated as members, both lying in the upper part of the formation. These are the Cautley Volcanic Member (defined in Millward, 2004) and the Wilsey Beck Sandstone Member.

Stratotype

The type section is in the Murthwaite Inlier in Wandale Beck and its tributaries between Odd Gill and the confluence with the River Rawthey [SD 6984 9806 to SD 6976 9965]; a reference section is in the Westerdale Inlier in Backside Beck [SD 699 998 to SD 698 979] (Ingham, 1966; Owen and Rushton, 1999).

Lithology

Massive and burrow-mottled blue-grey, calcareous mudstone, interbedded with layers of calcareous nodules that amalgamate into beds of micritic limestone up to 30 cm thick. The limestone contains an abundant benthic shelly fauna. Units of sandstone occur at the base and at a higher level in the succession, with the latter referred to as the Wilsey Beck Sandstone Member. A unit of rhyolitic tuff occurs in the top part of the formation and is referred to as the Cautley Volcanic Member.

Definition of lower boundary

The base is not proved with certainty because of extensive faulting throughout most of the area. However, Ingham (1966) suggested that the base may be present beneath the lowest bed of mudstone overlying a small exposure of purple andesite in a gill, 400 m north-north-east of Foggygill Farm [SD 7220 9880]; the andesite is tentatively assigned to the Borrowdale Volcanic Group.

Definition of upper boundary

Taken at the unconformity with overlying mudstone of the Ash Gill Mudstone Formation.

Thickness

Up to 570 m.

Genetic interpretation

The Cautley Mudstone Formation is equivalent to the first three depositional cycles seen in the southern Lake District (Kneller et al., 1994), representing continuous deposition in oxygenated marine water in an open shelf setting (Williams et al., 2001; Rickards and Woodcock, 2005).

Biostratigraphical characterisation

The limestone beds in particular contain a rich shelly benthic fauna of brachiopods, trilobites, bryozoans and corals which range from the Onnian (upper Caradoc), through the Pusgillian, Cautleyan and Rawtheyan stages of the Ashgill (Ingham, 1966), providing the most complete sequence of this age in northern England. Rickards (2002) assigned the rocks of Rawtheyan zones 5 and 6 of Ingham (1966) to the *linearis* Graptolite Biozone, and zone 7 possibly to the *complanatus* Biozone. He also stated that the graptolitic correlation of the Cautleyan shelly zones in the Cautley inliers was doubtful.

Age

Caradoc: Streffordian (Onnian) to Ashgill (Rawtheyan).

Geographical limits

Restricted to the Cautley and Dent inliers of the Howgill Fells, Cumbria.

Maps

Kendal, Kirkby Stephen, Kirkby Lonsdale, Hawes.

Regional correlation

The lower part is lithologically and biostratigraphically similar to the upper part of the Dufton Mudstone Formation and is also partially equivalent to the overlying Swindale and Keisley limestone formations in the Cross Fell Inlier. The correlated units in the Craven inliers include the Norber Formation and the lower part of the Sowerthwaite Siltstone Formation. The equivalent strata in the southern Lake District include all Dent Group formations beneath the Ash Gill Mudstone Formation.

6.3.1.1 WILSEY BECK SANDSTONE MEMBER

Name

The term Wilsey Beck Sandstone was first used by Ingham (1966) and given formation status in a figure in Ingham and McNamara (1978, fig. 43). The term was retained as a member of the Cautley Mudstone Formation by Kneller et al. (1994).

Stratotype

The only exposure, and therefore the type section is in Wilsey Beck [SD 6868 8748], 500 m north-west of Gawthrop (Woodcock and Rickards, 2006).

Lithology

Calcareous sandstone, interpreted as a storm-derived sand deposit.

Definition of lower boundary

Taken where sandstone becomes dominant in the passage from underlying mudstone within the Cautley Mudstone Formation.

Definition of upper boundary

The top is taken where mudstone within the Cautley Mudstone Formation becomes dominant in a passage upwards from sandstone.

Thickness

7 m.

Age

Ashgill (Cautleyan).

Distribution

Restricted to the Gawthrop Inlier, near Dent, Cumbria.

Maps

The unit is too thin to be shown on any 1:50 000 scale map, though it is depicted on the 1:10 000-scale map.

6.3.2 Ash Gill Mudstone Formation (AHL)

See Southern Lake District area (section 6.4.5) for the definition. A basal unit is recognised in the Cautley and Dent inliers as the Cystoid Limestone Member.

A unit of sandstone and conglomerate recorded from the upper part of the formation in the Taythes Inlier by Ingham (1966) is lithologically similar to the Wharfe Member (Sowerthwaite Siltstone Formation), in the Craven inliers. Kneller et al. (1994) speculated on their correlation, and on this basis the term Wharfe Member has been applied subsequently to the unit in the Taythes Inlier (e.g. Fortey et al., 2000). Since a member cannot belong to two formations the term Wharfe Member cannot be applied to a division of the Ash Gill Mudstone Formation. As such lithofacies may be very localised in their occurrence and diverse in origin, we have not proposed as new separate term for the unit identified by Ingham.

6.3.2.1 CYSTOID LIMESTONE MEMBER (CYO)

Name

The term Cystoid Limestone was introduced in the Cautley and Dent inliers by Ingham (1966) for the 'mucronatus band of the Staurocephalus group' of Marr (1913). The new name was justified for a number of reasons including the distinct trilobite assemblage compared with the older Staurocephalus Limestone beds from the Lake District with which Marr had correlated the unit, and the stratigraphical break at the base; cystoids are the most commonly found fossils (Ingham, 1966). Though the nominal epithet is not a geographical term, the term Cystoid Limestone is retained because it is entrenched in the literature.

Stratotype

Type section is in Odd Gill [SD 7146 9912], 300 m east of its confluence with Wandale Beck (Ingham, 1966).

Lithology

Pale grey argillaceous limestone containing an abundant calcareous shelly fauna that is dominated by cystoids.

Definition of lower boundary

Taken at the change in lithology from grey mudstone of the Cautley Mudstone Formation to limestone. Ingham (1966) showed that, across the various Cautley and Dent inliers, the limestone rests unconformably on the rocks beneath.

Definition of upper boundary

Taken at the change from limestone to grey mudstone of the Ash Gill Mudstone Formation.

Thickness

1.5 to 3 m.

Biostratigraphical characterisation

The limestone contains diploporitan and rhombiferan cystoids along with trilobites and brachiopods characteristic of the uppermost Rawtheyan stage (Ingham and Wright, 1972)

Age

Ashgill.

Geographical limits and regional correlation

Confined to the Howgill Fells, but is correlated with the Troutbeck Member in the Lake District.

Maps

The unit is too thin to be shown on any 1:50 000 scale map, though it is depicted on 1:10 000-scale maps.

6.4 SOUTHERN LAKE DISTRICT

The Dent Group in this area comprises seven formations: Stile End, Yarlside Volcanic, Kirkley Bank Limestone, Broughton Moor Limestone, Appletreeworth Volcanic, High Haume Tuff and Ash Gill Mudstone. These are the divisions adopted by Kneller et al. (1994), with the addition of the High Haume Tuff Formation in the Ulverston district (Johnson et al., 2001). The Kneller et al. scheme is based on that erected by McNamara (1979). Historically, the clastic and volcanic lower parts of the succession were included as part of what is now the Borrowdale Volcanic Group (Sedgwick, 1845, 1846b; Harkness and Nicholson, 1868, 1877), with the overlying calcareous rocks defined as the Coniston Limestone. However, following Aveline and Hughes (1872), the whole succession recognised today as the Dent Group was referred to as the Coniston Limestone Series (Marr, 1878, 1892a, 1916). The development of the current stratigraphy is charted by Kneller et al. (1994). Definitions of the Yarlside and Appletreeworth volcanic formations and the High Haume Tuff Formation are to be found in Millward (2004).

6.4.1 Stile End Formation (SEN)

Name

The Stile End Formation was designated by McNamara (1979) and the definition widened by Kneller et al. (1994) to accord more with Harkness and Nicholson's (1877) original definition of the 'Stile End Grassing Beds'. The last-named authors included these strata within what is now designated as the Borrowdale Volcanic Group. Aveline and Hughes (1888) referred to these beds as 'Calcareous Ash with fossils' but following Marr (1892a), this unit has been known traditionally as the Stile End Beds. Moseley (1984) divided the lower part of his Coniston Limestone Formation into Longsleddale and Stile End members, but included the Yarlside Volcanic Formation rocks in the latter, whereas Lawrence et al. (1986) maintained separate Longsleddale, Stile End and Stockdale Rhyolite (= Yarlside) members.

Formal subdivisions

Following Kneller et al. (1994), the Longsleddale Conglomerate Member is here included in the Stile End Formation. In addition, we transfer to this formation the lithologically similar sequence of rocks that crop out in the Furness district, and which were designated the Low Scales Member of the Kirkley Bank Formation by Johnson et al. (2001, p.45).

Stratotype

Type section is the sequence in and to the north of the disused quarries [NY 4887 0569] about 400 m north-north-west of Stockdale Farm, Longsleddale, Cumbria.

Lithology

Grey fossiliferous calcareous siltstone with interbedded nodular limestone and thin units of pebbly coarse-grained sandstone; a unit of conglomerate and sandstone in the lower part is designated the Longsleddale Conglomerate Member.

Definition of lower boundary

Taken at the base of the lowest bed of conglomerate or sandstone unconformably overlying rocks of the Borrowdale Volcanic Group.

Definition of upper boundary

Taken at the top of conglomerate and sandstone overlain either by the base of the Yarlside Volcanic Formation or by the basal carbonate rocks of the Kirkley Bank Limestone Formation.

Thickness

Up to a maximum of about 400 m.

Genetic interpretation

The formation represents the start of the first depositional cycle within the Dent Group (Kneller et al., 1994) and is preserved only within irregularities in the volcanic substrate. The basal Longsleddale Conglomerate Member records the local progradation of alluvial fans into an embayment of the sea, where wave action reworked the deposits. In the rest of the formation, coarse volcaniclastic sediment deposited in the near-shore region becomes gradually finer grained offshore, passing into a belt where calcareous mud accumulated.

Biostratigraphical characterisation

Shelly fossils are known only locally from the Longsleddale Conglomerate Member, but a more diverse assemblage that includes ten species of trilobite has been recorded from the main part of the formation (McNamara, 1979). These are taken to indicate a Cautleyan age, and at least as old as the shelly faunal zone 2 of Ingham (1966).

Age

Ashgill (Cautleyan).

Geographical limits

Along the southern margin of the Lake District, the main facies is confined to the area east of Troutbeck. The basal Longsleddale Conglomerate Member has a wider distribution.

Maps

Ambleside, Kendal.

6.4.1.1 LONGSLEDDALE CONGLOMERATE MEMBER (LSD)

Name

The status of this unit follows Kneller et al. (1994) in reducing the rank of McNamara's (1979) Longsleddale Formation and including it in the Stile End Formation. During the intervening

period, Moseley (1984) and Lawrence et al. (1986) had referred the Longsleddale Member to the Coniston Limestone Formation.

Stratotype

The type section [NY 4888 0670 to 4883 0583] is 450 m north-north-west of Stockdale Farm, Longsleddale (Lawrence et al., 1986).

Lithology

Interbedded, thick sequence of conglomerate, sandstone and siltstone composed essentially of detritus derived locally from the Borrowdale Volcanic Group. The conglomerate beds are poorly sorted in fining upwards cycles. The red and green coloured siltstone beds are sporadic but well laminated. Details of these beds in the Ambleside district are given by Millward et al. (2000, p. 119–123).

Definition of lower boundary

Taken at the base of conglomerate beds, unconformably overlying volcanic rocks of the Borrowdale Volcanic Group.

Definition of upper boundary

Abruptly gradational into the overlying part of the Stile End Formation; in places overlain unconformably by carbonate rocks of the Kirkley Bank Limestone Formation.

Thickness

0–65 m.

Age

Ashgill (Cautleyan).

Geographical limits and regional correlation

The main outcrop of the Longsleddale Conglomerate Member is from west of Kentmere to just east of Longsleddale. Sporadic occurrences of conglomerate are present at the base of the Dent Group along its outcrop from Furness to Shap, but these have not always been assigned to the member, as most are thin and their ages not clearly established. A thick siliciclastic unit in the Ulverston district, the Low Scales Sandstone Member, was included by Johnson et al. (2001, p. 45) in the Kirkley Bank Limestone Formation: however, it is most probably a lateral equivalent to the Longsleddale Conglomerate Member and accordingly is included here in the Stile End Formation.

Maps

Ambleside, Kendal.

6.4.1.2 Low Scales Sandstone Member (LWS)

Name

The term was introduced by Johnson et al. (2001, p. 45) for the substantial clastic sedimentary sequence at the base of the Dent Group in the Millom area of the south-west Lake District. They placed it in the Kirkley Bank Limestone Formation, but lithologically and stratigraphically it is more appropriately included in the Stile End Formation alongside the Longsleddale Conglomerate Member.

Stratotype

The type section is in Low Scales Beck [SD 1618 8141 to SD 1625 8129].

Lithology

Greenish grey, weakly bedded, coarse- and medium-grained volcaniclastic sandstone with subordinate conglomerate, siltstone and mudstone, and with a bed at the top of well sorted, white weathered feldspathic sandstone with sporadic shell detritus.

Definition of lower boundary

Taken at the base of the heterogeneous clastic sedimentary succession, unconformably overlying Borrowdale Volcanic Group rocks.

Definition of upper boundary

Taken at the abrupt, apparently conformable change to limestone at the base of the Kirkley Bank Limestone Formation.

Thickness

Up to about 160 m.

Age

Ashgill (Cautleyan).

Geographical limits

Waterblean to south of Beck Wood [SD 177 824 to 158 806], south-west Lake District.

Maps

Black Combe (1:25 000); Ulverston.

6.4.2 Kirkley Bank Limestone Formation (KKB)

Name and formal subdivisions

The rocks that are now included within this formation originally comprised the major part of the traditional Coniston Limestone, as introduced by Sedgwick (1845, 1846b), and Harkness and Nicholson (1877), and for which Marr (1892a) used the name Applethwaite Beds. Rose and Dunham (1977) referred to these rocks as the High Haume Mudstone and High Haume Limestone. The term Kirkley Bank Formation, designated after dwellings of that name just west of Windermere lake, was introduced by Scott and Kneller (1990) and Kneller et al. (1994), to associate together, as members, the Kentmere Limestone Member, and the Applethwaite, High Pike Haw and Torver formations of McNamara (1979). The Kentmere Limestone and Applethwaite members equate with the Calymene Beds, and the Torver Member with the Phillipsinella Beds, of Marr (1916). In Low Furness, the Kentmere Limestone Member has been referred to as the Ireleth Member (Kneller et al., 1994; Johnson et al., 2001, p. 45–46), after the Ireleth Limestone of Sedgwick (1846b). However, as these are direct correlations in adjacent areas, the term Ireleth Member is here considered unnecessary and designated as obsolete.

Stratotype

The type area [SD 2192 7544 to SD 2295 7669] is defined south-west of High Haume Farm, Dalton in Furness, Cumbria.

Lithology

Predominantly calcareous siltstone and mudstone, with nodules, beds and members of mostly impure limestone; fine-grained sandstone forms a small proportion of the sequence. The predominant calcareous rocks are divided into members on the basis of their lithofacies.

Definition of lower boundary

The base of the formation is taken at the base of the sequence of dominantly calcareous rocks that oversteps the Yarlside Volcanic Formation in the Longsleddale area, the underlying Stile End Formation and various local accumulations of conglomerate, to rest directly on the Borrowdale Volcanic Group.

Definition of upper boundary

This is taken at the base of the overlying Broughton Moor Limestone or High Haume Volcanic formations, or where these are not present, by the Ash Gill Mudstone Formation.

Thickness

Varies from about 20 m just north-east of Coniston (McNamara, 1979), up to about 220 m in Furness.

Genetic interpretation

The formation constitutes the second depositional cycle within the Dent Group (Kneller et al., 1994). The succession records the inundation of the eroded and subsiding Borrowdale volcanoes with deposition of the carbonate rocks during a period of restricted siliciclastic sediment supply, but which was episodically affected by storms.

Biostratigraphical characterisation

These rocks contain a rich benthic fauna in which McNamara (1979) recorded more than 30 species of trilobite. He assigned these to Ingham's (1966) Cautleyan Zone 2, with the exception of the upper, Torver Member which was placed in Zone 3.

Age

Ashgill (Cautleyan).

Geographical limits

The continuous narrow outcrop forms a belt along the southern margin of the Borrowdale Volcanic Group, from Furness in the south-west Lake District to Shap.

Maps

Black Combe, Coniston Fells (1:25 000 scale); Ambleside, Kendal, Ulverston.

Regional correlation

Equivalent in part to the Cautley Mudstone Formation of the Cautley and Dent inliers.

6.4.2.1 KENTMERE LIMESTONE MEMBER

Name

The definition (Kneller et al., 1994) is that of McNamara's (1979) Kentmere Limestone Member. Lawrence et al. (1986) recognised the presence in the Longsleddale area of the lithofacies that comprise this member, but did not formalise it. The definition herein includes the

High Haume Limestone of Rose and Dunham (1977) and the Ireleth Member of Johnson et al. (2001, p.47).

Stratotype

The type section is included within that for the Kirkley Bank Limestone Formation.

Lithology

Alternating beds of grey limestone, up to 20 cm thick, and dark grey mudstone; macrofossils appear to be absent but the microfauna is dominated by ostracods.

Definition of lower boundary

The base coincides with that of its parent, the Kirkley Bank Limestone Formation.

Definition of upper boundary

Taken at the change in lithofacies from limestone and interbedded mudstone to calcareous siltstone and shelly sandstone at the base of the Applethwaite Member in the east, or to the more siliciclastic siltstone at the base of the overlying High Pike Haw Member in the west of the outcrop.

Thickness

Up to about 21 m, but generally less.

Age

Ashgill (Cautleyan).

Distribution

As for the parent unit, Kirkley Bank Limestone Formation.

Maps

This unit is too thin to have been included on published geological survey maps. Its occurrence in the Ambleside district is recorded by Millward et al. (2000, p.123–124).

6.4.2.2 APPLETHWAITE MEMBER

Name

This definition follows Kneller et al. (1994), who reduced McNamara's (1979) and Moseley's (1984) Applethwaite Formation to member status. The term Applethwaite Beds was used originally by Marr (1892a), but this also included what is herein the Broughton Moor Limestone Formation. Lawrence et al. (1986) also used the term, but this included beds up to and including the Troutbeck Siltstone Member of the Ash Gill Mudstone Formation.

Stratotype

Type section in exposures to the east of the Garburn Road on Moor Head [NY 426 037], Applethwaite Common, Kendal (McNamara, 1979).

Lithology

Mainly a calcareous siltstone, but occurs in graded units that range from a fine-grained sandstone with shelly lag accumulations at the base, to a bioturbated and fine-grained top. Cross-bedding is widespread, and there are rare interbeds of concretionary limestone. The member is interpreted

as a sequence of storm-surge deposits. A lateral gradation into the High Pike Haw Member occurs over about 1.5 km between High Pike Haw [SD 264 949] and Torver Beck [SD 276 963].

Definition of lower boundary

The base is taken at the marked lithological change to graded calcareous rocks, either from the underlying concretionary limestone of the Kentmere Member, or from volcanic rocks of the Yarlside Volcanic Formation or Borrowdale Volcanic Group.

Definition of upper boundary

The upper boundary is taken at the top of the highest graded unit, which is gradational into the overlying uniform, bioturbated calcareous siltstone of the Torver Member.

Thickness

Up to about 60 m.

Age

Ashgill (Cautleyan).

Geographical limits

Southern Lake District, from Coniston [SD 300 980] to the Birkbeck Fells [NY 560 070].

Maps

This unit is too thin to have been included on published geological survey maps. Its occurrence in the Ambleside District is recorded by Millward et al. (2000, p.125).

6.4.2.3 HIGH PIKE HAW MEMBER

Name

This definition follows Kneller et al. (1994), who reduced McNamara's (1979) High Pike Haw Formation to member status.

Stratotype

The type section is on High Pike Haw [SD 263 947], south-west of Coniston (McNamara, 1979).

Lithology

In the south-west of the outcrop, over a distance of about 1.5 km between High Pike Haw [SD 264 949] and Torver Beck [SD 276 963], the Applethwaite Member grades laterally into the High Pike Haw Member which has a coarser siliciclastic component and a lower proportion of limestone beds. McNamara (1979) likened this unit to an admixture of the calcareous siltstone element of the Stile End Formation and interbedded nodular limestone of the Applethwaite Member.

Definition of lower boundary

The High Pike Haw Member rests conformably on the Kentmere Limestone Member and the base is taken above the highest limestone bed in the Kentmere Limestone Member.

Definition of upper boundary

The boundary is taken at the gradational base of the conformably overlying Torver Member.

Thickness

35 m in the type section to more than 100 m near Millom [SD 163 813].

Age

Ashgill (Cautleyan).

Geographical limits

South-west section of the Kirkley Bank Limestone Formation outcrop, from Furness north-east towards Torver Beck.

Maps

This unit is too thin to have been included on published geological survey maps. Its occurrence in the Ambleside District is described by Millward et al. (2000, p. 125).

Regional correlation

The member is the direct lateral equivalent of the Applethwaite Member.

6.4.2.4 TORVER MEMBER

Name

This definition follows Scott and Kneller (1990), and Kneller et al. (1994), who reduced McNamara's (1979) Torver Formation to member status. The member is equivalent to Marr's (1916) Phillipsinella Beds, so-called because of the abundance of the trilobite *Phillipsinella parabola aquilonia* (Ingham, 1970).

Stratotype

The type section is on the north-eastern side of Willy Scrow [SD 2934 9571], 1 km west of Coniston.

Lithology

Grey-brown weathered, bluish, thickly bedded calcareous siltstone; the variable carbonate content produces a patchy, honeycomb effect. No sedimentary structures are present and the rock is pervasively bioturbated. There is also a high content of fragmented bioclastic material, along with sparsely disseminated sand-sized quartz grains and rock fragments.

Definition of lower boundary

Taken at the base of the lowest unit of the typically honeycomb-weathered, pervasively bioturbated grey-brown calcareous siltstone, overlying the limestone-bearing, graded, calcareous siltstone and sandstone of either the High Pike Haw or Applethwaite members.

Definition of upper boundary

The upper boundary is taken at the base of the overlying Broughton Moor Formation, beneath which there is a depositional hiatus.

Thickness

3 to 8 m.

Age

Ashgill (Cautleyan).

Geographical limits

Seen within the Kirkley Bank Limestone Formation in its outcrop in the southern Lake District between Ashgill and Troutbeck.

Maps

This unit is too thin to have been included on published geological survey maps. Its occurrence in the Ambleside District is described by Millward et al. (2000, p. 125).

6.4.3 Broughton Moor Limestone Formation (BMR)

Name

This is a renaming by Scott and Kneller (1990), and Kneller et al. (1994) of the White Limestone Formation of McNamara (1979) and the White Limestone Member of Moseley (1984). The name White Limestone originates from Marr (1916).

Formal subdivision

The Lumholme Member is included, though some uncertainty remains about its correct affiliation.

Stratotype

Type section at Broughton Moor [SD 263 947], east of High Pike Haw, south-west Lake District (Scott and Kneller, 1990).

Lithology

Interbedded hard, pale grey, nodular and pervasively bioturbated, micritic limestone weathered with a white coating. At the base is a thin unit of chamositic ooids. Marr (1916) described these rocks as the most easily recognised of the Ashgill strata.

Definition of lower boundary

Taken at the base of this distinctive micritic limestone lithofacies, overlying an irregular surface on calcareous siltstone of the Torver Member of the Kirkley Bank Limestone Formation, indicating an unconformable relationship. Where locally the Torver Member passes up into the base of the Broughton Moor Limestone Formation, an horizon with chamositic ooids marks the junction (Millward et al., 2000, p. 125–126).

Definition of upper boundary

Overlain in the south-west by rhyolitic tuff of the Appletreeworth Volcanic Formation, but where this is absent to the north-east the Broughton Moor Limestone Formation is overlain by mudstone of the Ash Gill Mudstone Formation, suggesting a disconformable relationship.

Thickness

Up to 6 m.

Genetic interpretation

Also part of the second depositional cycle within the Dent Group (Kneller et al., 1994). The ooidal ironstone at the base is considered to have been deposited during the maximum marine transgression and the overlying limestone may represent condensed deposition (Kneller et al., 1994).

Biostratigraphical characterisation

A diverse shelly fauna with many trilobites has been recorded, but only locally, and this indicates a Rawtheyan Zone 5 or 6 age (Ingham, 1966).

Age

Ashgill (Rawtheyan).

Geographical limits

The outcrop is localised between Limestone Hill [NY 3405 0044], just east of Tarn Hows, Coniston, and Hobkin Ground Wood [SD 2297 9125], near Broughton Mills.

Maps

The formation is too thin to be shown on the published Ambleside and Ulverston 1:50 000 series maps, though it is shown in the Generalised Vertical Section of the first named sheet. The formation is depicted combined with the Appletreeworth Volcanic Formation on the 1:25 000-scale sheet for Coniston Fells.

Regional correlation

Biostratigraphically equivalent to part of the Cautley Mudstone Formation in the Cautley and Dent inliers.

6.4.4 Lumholme Conglomerate Member

The Lumholme Member was first introduced by Scott and Kneller (1990) for a locally occurring matrix-supported conglomerate up to 5 m thick in the area near Hartley Ground and Lumholme, Broughton Mills [SD 2145 8975], in the south-west of the Lake District. A detailed description of the unit is included as an appendix in Soper (1991). Interpreted as a debris-flow deposit, the conglomerate is composed of clasts of limestone, calcareous siltstone, black silty mudstone and volcanic rocks set in a sandy matrix with calcareous cement. Scott and Kneller considered this unit to be part of the Browgill Formation, but based on information from Armstrong et al. (1996), both Millward et al. (2000, p. 126) and Johnson et al. (2001, p. 48) placed it within the Broughton Moor Limestone Formation in the Ambleside and Ulverston districts respectively. In point of fact, Armstrong et al. (1996) had found that the Lumholme Member contains conodonts that indicated a mid to late Rawtheyan age and had concluded that the deposit could belong either to the Broughton Moor Limestone or to the lower part of the Ash Gill Mudstone formation. The parental affiliation of the Lumholme Conglomerate Member therefore remains uncertain.

This unit is too thin to have been included on published geological survey maps. Note that in Armstrong et al. (1996), Kneller et al. (1994) and Millward et al. (2000) the name is misspelt as Lumholm.

6.4.5 Ash Gill Mudstone Formation (AHL)

Name

Kneller et al. (1994) formalised this unit to consist of the Ashgill Beds of Salter (1873), defined as for the Ashgill Shale Formation of McNamara (1979), together with the underlying *Phacops mucronatus* Beds of Marr (1916), which was defined as the Troutbeck Formation of McNamara (1979). The Swindale Shales of the Cross Fell Inlier were included within the Ashgill Formation by Owen and Rushton (1999). Local details of the Ashgill Formation have been given by: Ingham (1966) and Rose and Dunham (1977) as the Ashgill Shales; Burgess and Holliday (1979) as the Swindale Shales; Lawrence et al. (1986) as the Ashgill Shale Member; and as the Ashgill Formation by Millward et al. (2000) and Johnson et al. (2001).

The use of biostratigraphical terms such as 'Ashgill' in lithostratigraphy is not recommended. Therefore, in this report, we use the geographical term Ash Gill to preserve the connection with its type locality.

Formal subdivisions

The basal carbonate-rich beds are defined as the Troutbeck Siltstone Member, which in the Cautley and Dent inliers is a distinctive limestone, termed the Cystoid Limestone Member. A coarse-grained sandstone unit, termed the Rebecca Sandstone Member, is present near the top of the formation in Low Furness. In the Taythes Inlier (Cautley and Dent), Ingham (1966) recorded a unit of sandstone and conglomerate in the upper part of the formation, subsequently termed the Wharfe Member (e.g. Fortey et al., 2000) on the basis of speculative correlation (Kneller et al., 1994) with the synonymous member of the Sowerthwaite Siltstone Formation in the Craven inliers (Arthurton et al., 1988). There is no clear evidence that these units are contemporaneous and because the term Wharfe Member cannot belong to two formations the unit of sandstone and conglomerate in the upper part of the Ash Gill Mudstone Formation remains undesignated herein (see also section 6.3.2). The Lumholme Conglomerate Member may also be associated with this formation (see above).

Stratotype

The type section is in Ashgill Quarry [SD 2690 9550] (Owen and Rushton, 1999). Reference sections are defined in Rebecca Quarry [SD 2292 7833] in the south-west Lake District (Johnson et al., 2001) and in Backside Beck [SD 699 998] (Owen and Rushton, 1999).

Lithology

Dark blue-grey mudstone, commonly pervasively bioturbated and distinguished from the underlying formations within the Dent Group by its lower carbonate content and the near absence of limestone nodules. A thin bentonite layer is present in the type section. Includes at the base a calcareous siltstone unit, locally with a basal nodular limestone facies containing bioclastic detritus. A coarse-grained sandstone unit occurs near the top of the formation in Furness.

Definition of lower boundary

The formation rests unconformably on rhyolitic tuff of the Appletreeworth Volcanic Formation in the south-west, overstepping north-eastwards across the white-weathered limestone of the Broughton Moor Limestone Formation to rest on bioturbated calcareous siltstone of the Kirkley Bank Limestone Formation.

Definition of upper boundary

Taken at the base of overlying black graptolitic mudstone of the Silurian Skelgill Formation.

Thickness

Generally less than 25 m, though variable from less than 2 m in Longsleddale to 215 m in the Ulverston district; about 25 m in the type section.

Genetic interpretation

This formation represents the fourth cycle within the Dent Group recording a regional rise in relative sea-level (Kneller et al., 1994) at a time when global sea levels were falling as a result of glaciation.

Biostratigraphical characterisation

The basal Troutbeck Siltstone Member contains bryozoans, brachiopods, trilobites, crinoids, cystoids and tentaculitids, and is richly fossiliferous locally, with monospecific bedding-plane assemblages of the trilobite *Mucronaspis* and the brachiopod *Hirnantia*. McNamara (1979) assigned a late Rawtheyan age to this member, within the upper part of Zone 7 of Ingham (1966). The upper part of the formation contains a relatively deep- and cold-water fauna of the *Hirnantia* brachiopod association (Brenchley and Cullen, 1984; Brenchley, 1988), probably associated with glaciations and assigned to the Hirnantian Stage.

Age

Ashgill (latest Rawtheyan and Hirnantian).

Geographical limits

Southern Lake District, Cross Fell and Cautley and Dent inliers.

Maps

Cross Fell, Coniston Fells, Black Combe, Dalton in Furness (1:25 000); Appleby, Brough under Stainmore (as Swindale Shales), Kirkby Stephen, Ulverston. Present but not depicted on Ambleside and Kendal within an undivided Dent Group.

Regional correlation

The Ash Gill Mudstone Formation is correlated with the uppermost part of the Sowerthwaite Siltstone Formation in the Craven inliers (Arthurton et al., 1988). The Rebecca Sandstone Member, Wharfe Conglomerate and sandstone and conglomerate in the Taythes Inlier may have been emplaced contemporaneously.

6.4.5.1 TROUTBECK SILTSTONE MEMBER

Name

Marr's (1892a) Staurocephalus Limestone and his Phacops mucronatus Beds (Marr, 1916) were formalised as the Troutbeck Formation by McNamara (1979), and reduced in rank and included within the Ashgill Formation by Kneller et al. (1994).

Stratotype

This is the basal unit of the Ash Gill Mudstone Formation and the type section is as for the parent (McNamara, 1979; Scott and Kneller, 1990; Kneller et al., 1994).

Lithology

Grey calcareous siltstone with bioclastic detritus scattered throughout; thin horizons of nodular limestone occur parallel to bedding, but these and the overall carbonate content decrease upwards.

Definition of lower boundary

The base is coincident with that of its parent, the Ash Gill Mudstone Formation.

Definition of upper boundary

The upper boundary is gradational, with the loss of carbonate content, passing up into dark blue-grey mudstone of the overlying main part of the Ashgill Formation.

Thickness

Up to 9 m.

Age

Ashgill (latest Rawtheyan).

Geographical limits

Present throughout the Lake District outcrop of the Ashgill Formation.

Maps

The member is too thin to be depicted on geological survey maps.

Regional correlation

The member is correlated with the Cystoid Limestone Member in the Cautley and Dent inliers.

6.4.5.2 REBECCA SANDSTONE MEMBER (REB)

Name

Defined by Johnson et al. (2001), formalising the Rebecca Grit of Rose and Dunham (1977).

Stratotype

The type area is defined as Rebecca Hill [SD 230 784], 1 km north-east of Ireleth.

Lithology

Medium to very coarse-grained sandstone in cross-laminated beds up to 0.5 m, and intercalated with thin mudstone beds; it is pebbly and conglomeratic locally.

Definition of lower boundary

Taken at base of lowest sandstone bed overlying silty mudstone of the main part of the Ash Gill Mudstone Formation.

Definition of upper boundary

Over much of its outcrop the member lies at the top of the Ash Gill Mudstone Formation and its top is therefore defined by the base of the overlying sequence of black graptolitic mudstone of the Skelgill Formation.

Thickness

Up to 50 m.

Age

Ashgill (Hirnantian).

Geographical limits

Restricted to the Askham in Furness area, Cumbria.

Maps

Dalton in Furness (as Rebecca Grit) (1:25 000); Ulverston.

6.5 CRAVEN INLIERS

Dent Group rocks that crop out in the Clapham Beck, Crummack Dale and Austwick–Ribblesdale inliers were previously referred to the Coniston Limestone Series by King and Wilcockson (1934). During the resurvey (Arthurton et al., 1988) the sequence was reclassified into two formations, the Norber Formation, and the overlying Sowerthwaite Siltstone Formation.

6.5.1 Norber Formation (NORB)

Name

This term was introduced by Arthurton et al. (1988) for rocks previously included by King and Wilcockson (1934) within the Coniston Limestone Series.

Formal subdivision

The basal carbonate unit is designated as the Crag Hill Limestone Member.

Stratotype

The type section was designated by Kneller et al. (1994) between Norber Brow and Wharfe Gill, about 1 km north-east of Austwick [SD 7960 6977 to SD 7877 6912]. A reference section is defined in Douk Ghyll, Horton in Ribblesdale [SD 8140 7237 to SD 8156 7243].

Lithology

Calcareous siltstone and argillaceous limestone with a shelly fauna. There is a siliceous conglomerate up to 6 m thick at the base.

Definition of lower boundary

Taken at the irregular base of the conglomerate in Douk Ghyll, Horton, unconformably overlying sandstones of the Ingleton Group. Elsewhere, the base of the formation is not seen.

Definition of upper boundary

Taken where calcareous siltstone and argillaceous limestone pass up into mudstone and siltstone at the base of the overlying Sowerthwaite Siltstone Formation.

Thickness

Up to 160 m.

Biostratigraphical characterisation

A rich shelly fauna obtained from the Douk Ghyll section is indicative of the Rawtheyan Stage (Arthurton et al., 1988, p. 5–7), within zones 5 or 6 of Ingham (1966).

Age

Ashgill (Cautleyan to Rawtheyan).

Geographical limits

Restricted to the Craven inliers, North Yorkshire.

Maps

Hawes, Settle.

Regional correlation

The Norber Formation is biostratigraphically equivalent to part of the Cautley Mudstone Formation of the Cautley and Dent inliers, and to the Broughton Moor Limestone Formation in the southern Lake District.

6.5.1.1 CRAG HILL LIMESTONE MEMBER (CRHL)

Name

The Crag Hill Limestone was described by King and Wilcockson (1934) and included in their Coniston Limestone Series. Arthurton et al. (1988, p. 5–6) formalised this unit as a member of the Norber Formation.

Stratotype

The type section is the west side of Ribblesdale, north-west of Crag Hill Farm [SD 8061 7097 to SD 8016 7155].

Lithology

Nodular-bedded argillaceous limestone with siltstone partings, containing a shelly calcareous fauna.

Definition of lower boundary

Not seen in any of the outcrops, but presumed to overlie calcareous siltstone of the Norber Formation.

Definition of upper boundary

Defined by the base of siltstones and mudstones of the overlying Sowerthwaite Siltstone or Skelgill Mudstone formations.

Thickness

At least 30 m.

Age

Ashgill.

6.5.2 Sowerthwaite Siltstone Formation (SOW)

Name

The term was introduced by Arthurton et al. (1988) and named after the eponymous farm [SD 7757 6988]. These rocks had been previously included within the Coniston Limestone Series of King and Wilcockson (1934).

Formal subdivisions

Three members are identified: the Jop Ridding Sandstone and the Dam House Bridge Tuff members at the base and the Wharfe Conglomerate Member. The Dam House Bridge Tuff Member has been defined in Millward (2004).

Stratotype

The type section, defined by Kneller et al. (1994), is the best exposed section of the formation in Austwick Beck [SD 7798 6953 to SD 7795 6969].

Lithology

Siltstone and mudstone with interbedded volcaniclastic rocks (Dam House Bridge Tuff Member), sandstone (Jop Ridding Sandstone Member) and conglomerate (Wharfe Conglomerate Member).

Definition of lower boundary

Taken at the base of the volcaniclastic rocks of the Dam House Bridge Tuff Member or at the base of the tuffaceous sandstone of the Jop Ridding Sandstone Member. This boundary overlies an unconformity overlying carbonate-rich rocks of the Norber Formation (Kneller et al., 1994).

Definition of upper boundary

Defined by the base of the overlying Silurian Skelgill Formation, which in the Craven inliers was formerly the lower part of the Crummack Formation of Arthurton et al. (1988, p. 11).

Thickness

Up to 300 m.

Biostratigraphical characterisation

Arthurton et al. (1988) recorded a sparse Rawtheyan shelly fauna from the lower part of the formation, indicative of zones 6 and 7 of Ingham (1966). The succession above the Wharfe Conglomerate Member contains an Hirnantian fauna (Arthurton et al., 1988).

Age

Ashgill (Rawtheyan and Hirnantian).

Geographical limits

Restricted to the Craven inliers.

Maps

Hawes, Settle.

Regional correlation

The upper part of the formation is equivalent to the Ash Gill Mudstone Formation elsewhere.

6.5.2.1 JOP RIDDING SANDSTONE MEMBER (JRSA)

Name

This term was introduced by Arthurton et al. (1988) and named after the location of the type section.

Stratotype

The type area is Jop Ridding Farm, about 1 km north-east of Austwick [SD 7831 6897].

Lithology

Massive greenish or purplish grey, medium-grained volcaniclastic sandstone, poorly sorted but with a weak lamination locally.

Definition of lower boundary

Taken at the base of the tuffaceous sandstone, unconformably overlying the siltstone and limestone sequence of the Norber Formation.

Definition of upper boundary

Taken at the base of overlying siltstone and mudstone of the main part of the Sowerthwaite Siltstone Formation.

Thickness

40 to 250 m.

Age

Ashgill (Rawtheyan).

6.5.2.2 WHARFE CONGLOMERATE MEMBER (WFC)

Name

The term was introduced by King and Wilcockson (1934) and described further by Arthurton et al. (1988).

Stratotype

The type section is at Austwick Beck Head [SD 7764 7186], in the Austwick inlier (Arthurton et al., 1988, p. 11).

Lithology

Well cemented pebble conglomerate with a sandy matrix. Round to subround clasts include underlying Dent Group lithologies, Ingleton Group, vein quartz and andesite.

Definition of lower boundary

Taken at the base of conglomerate, resting on an erosion surface within siltstones of the Sowerthwaite Siltstone Formation.

Definition of upper boundary

Taken at the lithology change to overlying well laminated sandy siltstone of the main part of the Sowerthwaite Siltstone Formation.

Thickness

Up to 2 m.

Age

Ashgill (Hirnantian) based on the Zone 8 fauna from strata immediately overlying the conglomerate.

Regional correlation

Kneller et al. (1994) speculatively correlated the Wharfe Conglomerate Member directly with similar lithofacies in the upper part of the Ash Gill Mudstone Formation (see section 6.4.5).

7 Stockdale Group

Throughout the whole region the Stockdale Group is divided into the Skelgill and Browgill mudstone formations (Figure 10).

7.1 SKELGILL MUDSTONE FORMATION (SKB)

Name

This is a formalisation of Skelgill Beds, a term used since its introduction by Nicholson and Lapworth (1875) for the 'Graptoliferous Mudstones' of Harkness and Nicholson (1868). Descriptions of the formation made as a result of the resurvey of the region are by Lawrence et al. (1986), Millward et al. (2000), Johnson et al. (2001), and Rickards and Woodcock (2005); these works cite previous studies on these rocks. Important biostratigraphical contributions are by Rickards (1970a) and Hutt (1974, 1975). This definition also includes rocks in the Craven inlier previously assigned by Arthurton et al. (1988) to the Hunterstye Member of the Crummack Formation.

Formal subdivision

The calcareous Spengill Mudstone Member is defined at the base.

Stratotype

The type section is Holbeck Gill [NY 3932 0292 to NY 3989 0342], upstream from High Skelghyll Farm (Marr and Nicholson, 1888).

Lithology

Laminated and massive mudstone and siltstone with subordinate calcareous siltstone laminae; black and dark grey, carbonaceous and slightly calcareous and locally pyritic. The mudstone is commonly rich in graptolites, but lacks a shelly fauna. The graptolites are preserved as pyritic casts or are flattened as chloritic films. The widespread, thin, impure limestone at the base is termed the Spengill Mudstone Member and immediately overlying this is a 20 mm thick lamina of bentonitic claystone. In the middle part of the formation in many sections throughout the region is a lamina of pale green-weathered mudstone, termed the 'Green Streak' (Marr and Nicholson, 1888; Rickards, 1964, 1970a). This has been reported apparently from the same horizon in the central Wales basin (Rickards, 1978) and in the Southern Uplands of Scotland (Spencer, 1966).

Definition of lower boundary

Taken at the base of the Spengill Mudstone Member, overlying mudstones of the Ash Gill Mudstone Formation. The abrupt lithological and faunal contrast between the blue-grey bioturbated mudstone of the Ash Gill Mudstone Formation and the thin impure limestone with its shelly fauna at the base of the Skelgill Formation was formerly thought to indicate an unconformable relationship (e.g. Aveline and Hughes, 1888), though this has subsequently been disproved by detailed biostratigraphy.

Definition of upper boundary

Succeeded conformably by the Browgill Mudstone Formation and taken at the sharp change from black mudstone to pale green mudstone.

Thickness

10 to 20 m in the Lake District, though it is locally up to 40 m in the Coniston area. Thickness in the Lake District is considered to have been affected by the presence almost everywhere of a tectonic discontinuity (Stockdale Thrust) nearly parallel to bedding (Millward et al., 2000). Up to 120 m are recorded in the Cautley and Dent inliers, but only about 15 m in the Craven inliers.

Genetic interpretation

The basal Spengill Mudstone Member is a condensed carbonate sequence with a deep-water low-diversity shelly benthos (Scott and Kneller, 1990). Deposition in an anaerobic sea floor environment has been inferred widely for the overlying black mudstones, though dysaerobic conditions may have prevailed at times during deposition of the grey mudstone intercalations (Rickards, 1964; Scott and Kneller, 1990; Rickards and Woodcock, 2005).

Biostratigraphical characterisation

Historically, the *persculptus* Graptolite Biozone age for the Spengill Mudstone Member placed it at the base of the Silurian. However, the international base of the Silurian System is taken at the base of the *acuminatus* Graptolite Biozone fauna which is proved within the Skelgill Mudstone Formation just above the bentonitic claystone on top of the Spengill Mudstone Member (Rickards, 1970a). Thus, the Spengill Mudstone Member is uppermost Ordovician. The succeeding part of the formation spans the *acuminatus* to *sedgwickii* biozones (Rickards 1970a, 1973). The 'Green Streak' lies within the *argenteus* Biozone (Rickards and Woodcock, 2005).

Age

Late Ashgill (Hirnantian) and Llandovery (Rhuddanian and Aeronian).

Geographical limits

The formation is seen across the southern Lake District, in the Cross Fell, Cautley and Dent, and Craven, inliers.

Maps

Black Combe (undivided group), Coniston Fells, Cross Fell, Dalton in Furness (1:25 000); Appleby, Brough under Stainmore, Ambleside, Kendal, Kirkby Stephen, Ulverston, Hawes (all undivided group), Settle (as Crummack Formation).

7.1.1 Spengill Mudstone Member (SPN)

Name

The term Spengill Member was introduced by Scott and Kneller (1990) and formalised by Kneller et al. (1994) to include the Atrypa flexuosa Band of Marr and Nicholson (1888) and the Basal Beds of Rickards (1970a; 1988). It is named after the location of its type section in Spen Gill. The Spengill Mudstone Member is also recognised in the Craven inliers, though previously it was placed there within the Crummack Formation (Arthurton et al., 1988; Kneller et al., 1994).

Stratotype

The type section is in Spen Gill [SD 6986 9978] in the Howgill Fells (Rickards, 1988).

Lithology

Pale to dark grey pyritous mudstone, bioturbated with thin units of nodular limestone containing a low-diversity deep-water shelly benthos fauna (Scott and Kneller, 1990).

Definition of lower boundary

The base of the member and that of the formation is taken at the base of this unit of nodular limestone overlying grey mudstone of the Ash Gill Mudstone Formation.

Definition of upper boundary

Taken at the sharp change from paler grey mudstone with limestone of the Spengill Member to black mudstone of the main part of the Skelgill Mudstone Formation. Where exposure is good, the base of the main part of the main part of the formation is marked by the presence of a thin unit of bentonitic claystone.

Thickness

7.5 cm to 2.5 m in the Ambleside district; 0.4 to 1.8 m in the Howgill Fells.

Age

Ashgill (Hirnantian) (see discussion in parent formation).

Geographical limits

Present throughout the region.

Maps

Too thin to be depicted on published maps.

7.2 BROWGILL MUDSTONE FORMATION (BRW)

Name

The name is taken from Brow Gill in Longsleddale and is the formalisation by Kneller et al. (1994) of Browgill Beds, first used by Marr and Nicholson (1888) for the Knock Beds of Nicholson and Lapworth (1875). Descriptions from the resurvey are by Lawrence et al. (1986), Millward et al. (2000), Johnson et al. (2001), and Rickards and Woodcock (2005). These works cite other important references to this unit, including that of Wilson (1954), Hutt (1974, 1975) and Rickards (1964; 1970a; 1973). This definition also includes rocks in the Craven inlier previously assigned by Arthurton et al. (1988) to the Capple Bank Member of the Crummack Formation.

Formal subdivisions

Includes the Hebblethwaite and Far House members, both in the upper part of the formation.

Stratotype

The type section was nominated by Nicholson and Lapworth (1875) at The Rake, in Brow Gill, [NY 4974 0587] but they also indicated a confirmatory (reference) section nearby in Stockdale Beck [NY 4919 0549]. This arrangement was adopted by Scott and Kneller (1990) and Kneller et al. (1994), though Lawrence et al. (1986) reported the Stockdale section as being more complete and easier to examine.

Lithology

Grey-green or red mudstone and siltstone with interbedded subordinate beds of black graptolitic mudstone. The green mudstone has a wispy bioturbated fabric. Small, diagenetic calcareous nodules occur throughout and bentonitic beds are common in the lower part of the formation (Lawrence et al., 1986). A concentration of siderite nodules is present about two thirds of the way up the sequence in the Ambleside district. In the Howgill Fells, red mudstone and siltstone form a coherent lenticular mapping unit within the upper part of the formation and this is

designated the Hebblethwaite Mudstone Member (Rickards and Woodcock, 2005). In the Kentmere and Longsleddale area the red beds become discontinuous (Lawrence et al., 1986) and farther south-west only a few red laminae are present. The uppermost part of the formation comprises grey beds, without intercalated black mudstone, and this is termed the Far House Siltstone Member.

Definition of lower boundary

Taken at the sharp change from black graptolitic mudstone of the underlying Skelgill Mudstone Formation to pale grey-green mudstone.

Definition of upper boundary

Taken at the first appearance of interlaminated hemipelagic mudstone and siltstone of the Brathay Mudstone Formation, above the grey siltstone of the Far House Siltstone Member.

Thickness

50 to 90 m south-west of Coniston, 38 to 100 m in the Kendal district, up to 80 m in the Howgill Fells, and about 20 m in the Craven inliers.

Genetic interpretation

The base of the formation coincides with the input of larger amounts of fine clastic material into the basin, probably from low-concentration turbidity flows. The intercalated sandstone beds indicate increased energy levels (Rickards and Woodcock, 2005). Anaerobic bottom-water conditions continued, but the green mudstone with its shelly benthos and extensive bioturbation records higher oxygen contents (see Millward et al., 2000 and Rickards and Woodcock, 2005 for more detailed summary).

Biostratigraphical characterisation

The dark mudstone units in the lower part of the formation contain graptolite faunas indicative of the *turriculatus* s.l. and *crispus* biozones (Rickards 1970a, 1973). In the Howgill Fells, Wilson (1954) demonstrated that strata underlying the red beds of the Hebblethwaite Mudstone Member are of *griestoniensis* Graptolite Biozone age, and Rickards (1973) recorded *crenulata* Biozone graptolites from the red beds. Rare phacopid trilobites and brachiopods have also been recorded from the Hebblethwaite Siltstone Member. The Far House Siltstone Member is assumed to lie within the *crenulata* Biozone, as it is overlain by the basal Wenlock *centrifugus* Biozone at the base of the overlying Brathay Mudstone Formation.

Age

Llandovery (Telychian).

Geographical limits

The formation is seen across the southern Lake District, in the Cross Fell, Cautley and Dent, and Craven, inliers.

Maps

Black Combe (undivided group), Coniston Fells, Dalton in Furness (1:25 000); Penrith, Appleby, Brough under Stainmore, Ambleside, Kendal, Kirkby Stephen, Ulverston, Hawes (all undivided group), Settle (as Crummack Formation).

7.2.1 Hebblethwaite Mudstone Member (HBW)

Name

The member was introduced by Rickards and Woodcock (2005) in the Howgill Fells for the part of the formation previously referred to as the 'Red Beds'; the name was taken from the location of the type section. Detailed descriptions had been provided previously by Wilson (1954) and Rickards (1964, 1970a, 1973) and by Rickards and Woodcock (2005).

Stratotype

The type section is in Hebblethwaite Hall Gill, Howgill Fells [SD 6910 9317 to SD 6910 9318].

Lithology

Massive red-brown and purple-red mudstone with sporadic layers of calcareous nodules.

Definition of lower boundary

Taken at the abrupt change to red mudstone from the typical grey-green mudstone of the main part of the Browgill Mudstone Formation below.

Definition of upper boundary

Taken at the abrupt change from red mudstone to massive grey mudstone of the Far House Siltstone Member.

Thickness

Up to 20 m.

Biostratigraphical characterisation and age

Rickards (1973) recorded *crenulata* Biozone graptolites from the member, indicating a late Telychian age. Rare phacopid trilobites and brachiopods have also been recorded (Rickards and Woodcock, 2005).

Geographical limits

Recognised as a lithostratigraphical unit only in the Howgill Fells, though the lithofacies is present at least as far west as Kentmere.

Maps

Too thin to be shown on published Geological Survey maps, though it is used on 1:10 0000-scale maps.

7.2.2 Far House Siltstone Member (FARH)

Name

The term was introduced by Scott and Kneller (1990) in the Ambleside district for the distinctive uppermost part of the formation that had been recognised in the Howgill Fells by Wilson (1954) and Rickards (1964) as the 'grey beds'. Hutt (1974, 1975) later demonstrated that the Far House Siltstone Member could be mapped across the Lake District. The name, included by Kneller et al. (1994), is taken from the location of the type section.

Stratotype

Type section [SD 3215 9857] in exposures in Far House Plantation, north-east of Coniston.

Lithology

Massive, hard, dark grey siltstone, unfossiliferous in many places though it has yielded trilobite fragments in the Howgill Fells (Wilson, 1954). The unit lacks the intercalated black graptolitic mudstone beds seen in the main part of the formation.

Definition of lower boundary

Taken at the first appearance of massive dark grey siltstone which in the Howgill Fells overlies red mudstone of the Hebblethwaite Siltstone Member.

Definition of upper boundary

Taken below the first appearance of hemipelagic mudstones of the overlying Brathay Mudstone Formation.

Thickness

2 m to about 10 m.

Biostratigraphical characterisation and age

The Far House Siltstone Member is assumed to lie within the *crenulata* Graptolite Biozone and is thus late Telychian in age. This is based on the fact that the overlying basal part of the Brathay Mudstone Formation has yielded *centrifugus* Biozone graptolites.

Geographical limits

Occurs throughout the southern Lake District, Howgill Fells and in the Craven inliers.

Maps

Too thin to be shown on published Geological Survey maps, though it is used on 1:10 000-scale maps.

8 Tranearth Group

The Tranearth Group is wholly divided into formations (Figure 10). In the southern Lake District, Cross Fell and Howgill Fells these include the Brathay Mudstone, Birk Riggs Sandstone, Coldwell Siltstone and Wray Castle Mudstone formations, whereas in the Craven inliers the group comprises the Brathay Mudstone, Austwick Sandstone, Coldwell Siltstone and Horton Siltstone formations.

8.1 SOUTHERN LAKE DISTRICT, CROSS FELL, AND CAUTLEY AND DENT INLIERS

8.1.1 Brathay Mudstone Formation (BRF)

Name

Marr (1878) first used the term Brathay Flags, named from the occurrence at Brathay Quarries. This has been used by subsequent authors (Blackie, 1933; Furness et al., 1967). Moseley (1984) formalised the unit as the Brathay Flags Formation but Lawrence et al. (1986) preferred Brathay Flag Formation. Kneller et al. (1994) omitted the term Flag(s) from their name. Recent descriptions of the formation by Lawrence et al. (1986), Millward et al. (2000), Johnson et al. (2001), and Rickards and Woodcock (2005) provide a rich source of older references to this unit. The definition of the Brathay Mudstone Formation herein follows Kneller et al. (1994) who extended the formation to include the hemipelagic rocks of the lower part of the Austwick Formation (Craven inliers) of Arthurton et al. (1988).

Formal subdivisions

The Dixon Ground Siltstone Member is recognised at the base of the formation.

Stratotype

Kneller et al. (1994) gave the type section as the continuously exposed sequence in Ash Gill Beck [SD 2711 9525 to SD 2728 9505] on Torver High Common, 1.5 km north-west of Torver. Marr's (1878) original type section in Brathay Quarries [NY 357 016] is retained as a reference section.

Lithology

Laminated graptolitic siltstone consisting of about three alternations per millimetre of terrigenous muddy siltstone and carbonaceous mudstone. This is interbedded with thin units of homogeneous mudstone or graded siltstone to mudstone that are interpreted as the deposits of low-density turbidity currents. The basal 10 to 30 m comprise a facies that is transitional between the underlying Far House Siltstone Member of the Browgill Mudstone Formation and the typical lithofacies of the Brathay Mudstone Formation. This was recognised and mapped by Wilson (1954) and Rickards (1964; 1967; 1970b) and formalised as the Dixon Ground Member by Kneller (1990a) and Kneller et al. (1994). About 15 m or so above the top of the Dixon Ground Member is a distinctive band of calcareous nodules. Bentonitic beds mostly less than one centimetre thick occur sporadically.

Definition of lower boundary

The base of the formation is taken at the first occurrence of hemipelagic graptolitic mudstone above the unfossiliferous green mudstone of the Browgill Mudstone Formation.

Definition of upper boundary

For much of the Lake District outcrop, the Brathay Mudstone Formation is overlain by turbiditic sandstone of the Birk Riggs Sandstone Formation and in these areas the upper boundary of the Brathay Mudstone Formation is taken below the first incoming of sandstone within the succession. From Kentmere eastwards to the A6 road at Shap, the Brathay Mudstone Formation is overlain by the Coldwell Siltstone Formation and the contact is taken below the first appearance of calcareous siltstone. East of the A6, where the Coldwell Siltstone Formation cannot be readily discerned, the Brathay Mudstone Formation is lithologically indistinguishable from the overlying Wray Castle Mudstone Formation with which it merges (Soper, 1999).

Thickness

100 to 320 m.

Genetic interpretation

Sedimentation is widely considered to have been in anaerobic conditions, either from hemipelagic fallout or dilute turbidity currents; the lamination may represent episodic fluctuations in the supply of silt and organic matter (e.g. Rickards, 1964; Dimberline et al., 1990; King, 1992).

Biostratigraphical characterisation

Graptolite faunas span the range from *centrifugus* to *lundgreni* biozones (Rickards, 1964, 1967, 1969, 1970; Lawrence et al., 1986). The basal Dixon Ground Siltstone Member is presumed to be confined to the lowest of these zones as it is overlain by laminated siltstone containing a *centrifugus* Graptolite Biozone fauna. The range in the Craven inliers is more restricted, with the incoming of sand (Austwick Sandstone Formation) much earlier in the Wenlock than elsewhere in the region: no later than *rigidus* and perhaps as early as *centrifugus* Graptolite Biozone (King and Wilcockson, 1934; Arthurton et al., 1988; Kneller et al., 1994).

Age

Wenlock (Sheinwoodian to Homerian) though Zalasiewicz et al. (2009) include the *centrifugus* Biozone within the uppermost part of the Llandovery (Telychian) (Table 2).

Geographical limits and regional correlation

From west of Ulverston in the south-west of the Lake District to Shap, and in the Howgill Fells. The redefinition of the Austwick Formation of Arthurton et al. (1988) by Kneller et al. (1994) extends the Brathay Mudstone Formation into the Craven inliers.

Maps

Black Combe, Coniston Fells, Cross Fell, Dalton in Furness (1:25 000); Appleby, Brough under Stainmore, Ambleside, Kendal, Kirkby Stephen, Ulverston, Kirkby Lonsdale, Settle (as part of the Austwick Formation).

8.1.1.1 DIXON GROUND SILTSTONE MEMBER (DGD)

Name

Introduced by Kneller (1990a) and formalised by Kneller et al. (1994) for the lower beds of the Brathay Mudstone Formation and named after the location of the type section. The nature of this basal unit had been recognised and mapped across the Howgill Fells and Lake District by Rickards (1967; 1970b). Rickards (1967) identified a *centrifugus* Graptolite Biozone fauna from the lowest hemipelagic beds in the member, indicating the base of the Wenlock Series.

Stratotype

The type area is the hillside immediately west of Dixon Ground [SD 2993 9758], which is about 200 m west of Coniston village, and a reference section lies immediately east of the track leading north from Knipe Fold [NY 3400 0015], about 1 km east of Tarn Hows (Kneller, 1990a).

Lithology

Pale to dark grey muddy siltstone and mudstone, thoroughly bioturbated and homogeneous in the lower part, becoming streaky and more clearly banded upwards with recognisable burrows in the least bioturbated parts. In the upper parts bioturbated zones alternate with laminated siltstone with the latter becoming dominant at the top. Within the uppermost one metre is a 10 cm thick slightly calcareous mudstone with carious weathering, seen throughout the northern England outcrops of the Brathay Mudstone Formation; it has been correlated with a similar horizon in the Builth inlier in Wales (Rickards and Woodcock, 2005).

Definition of lower boundary

As for the base of the Brathay Mudstone Formation which it marks.

Definition of upper boundary

Transitional into the typical laminated mudstone facies of the Brathay Mudstone Formation.

Thickness

10 to 30 m.

Age

Wenlock (Sheinwoodian).

Distribution

Southern Lake District and Howgill Fells.

Maps

Coniston Fells (1:25 000). This unit has not been shown on Geological Survey 1:50 000-scale maps.

8.1.2 Birk Riggs Sandstone Formation (BKR)

Name

The term was introduced and defined by Kneller (1990a) and included in the scheme of Kneller et al. (1994). The formation approximates to the Lower Coldwell Beds of Marr (1878) and to the Grit Band 1 of Aveline and Hughes (1872). In the Ulverston district, these rocks were assigned previously to the Gawthwaite Sandstone Formation of Norman (1963) and the Harlock Grits of Rose and Dunham (1977). Recent descriptions of the formation are included in Lawrence et al. (1986, as Lower Coldwell Beds), Johnson et al. (2001) and Millward et al. (2000).

Stratotype

The type section is the open ground at Birk Riggs, [SD 2781 95501 to SD 2811 95401] (Kneller, 1990a).

Lithology

The lithofacies range from laminated mudstone and siltstone to sandstone in graded beds of increasing grain-size and bed thickness up to massive, very thick-bedded and amalgamated units (i.e. without finer-grained interbeds); interbedded with these is a subordinate to dominant

background of laminated hemipelagite. Units rich in sandstone or siltstone and mudstone can be traced for considerable lengths at outcrop, but these do not occur consistently at a particular level within the formation. Along part of the outcrop, the uppermost 25 m comprises laminated hemipelagic mudstone.

Definition of lower boundary

Taken at the change from laminated hemipelagite of the Brathay Mudstone Formation to turbidite sandstone lithofacies. In part this is represented by 'expanded hemipelagite', in which up to 25 per cent thin, fine-grained turbidite sandstone beds are intercalated with laminated hemipelagite.

Definition of upper boundary

Defined by the base of homogeneous calcareous siltstone of the Coldwell Siltstone Formation overlying sandstone. In part of the outcrop of the Birk Riggs Sandstone Formation the change is from laminated hemipelagite to calcareous siltstone.

Thickness

0 to 360 m.

Genetic interpretation

The formation represents a set of small, coalescing turbidite fans, with the thickly bedded sandstone deposited from high-density currents and the siltstone-mudstone facies from lower density currents in the fringes of the fan or in channel overbank areas (Millward et al. 2000).

Biostratigraphical characterisation

Graptolites recovered from the siltstone–mudstone facies and from the hemipelagic unit at the top are indicative of the *lundgreni* Biozone (Rickards, 1969, 1970b).

Age

Wenlock (Homerian).

Distribution

South-west Lake District, from Furness to just east of Longsleddale.

Maps

Dalton in Furness (as Harlock Grits), Black Combe, Coniston Fells (1:25 000); Ulverston, Ambleside, Kendal.

Regional correlation

Kneller et al. (1994) correlated their redefined Austwick Formation with the Birk Riggs Sandstone Formation, though recognising the earlier onset of the former.

8.1.3 Coldwell Siltstone Formation (CDW)

Name

Kneller (1990a) and Kneller et al. (1994) reverted to the original use of the term Coldwell Beds by Aveline and Hughes (1872). Marr (1878) introduced the term Middle Coldwell Beds for these rocks, but there is uncertainty where he defined the boundaries. Lawrence et al. (1986) defined their Middle Coldwell Beds in the way proposed by Kneller et al. The present definition of the formation is not equivalent to the Coldwell Formation of Moseley (1984). The Arcow Formation of McCabe (1972) and Arthurton et al. 1988) is subsumed herein into the Coldwell Siltstone

Formation because of lithological and faunal similarities. The former name becomes redundant (Appendix 3).

Formal subdivisions

Kneller (1990a) designated two formal units, the High Cross and Randy Pike members, but these carry the main lithology of the formation. Despite their adoption by Kneller et al. (1994) and Millward et al. (2000), their continued use is not recommended herein (see Appendix 3).

Stratotype

Aveline and Hughes (1872) defined their Coldwell Beds from Cold Well Quarry [NY 359 010] near Hawkshead and Kneller (1990a) extended this to include the ground up to the ridge 250 m to the west. Kneller (1990a) also provided an alternative type section on Birk Riggs [SD 2808 9536 and SD 2814 9529] which is herein recommended as a reference section. The Wandale Hill [SD 7000 9890 to 6877 9098] occurrence in the Howgill Fells (Rickards and Woodcock, 2005) is herein recommended as a reference section because of its rich fauna.

Lithology

Two units of pale blue-grey, calcareous fine- to coarse-grained siltstone with a mottled appearance due to pervasive bioturbation, separated by a unit of laminated muddy siltstone (hemipelagite). Sporadic bentonite beds occur through the middle part of the formation. The calcareous siltstone units contain a rich calcareous fauna locally.

Definition of lower boundary

Where the Coldwell Siltstone Formation overlies the Birk Riggs Sandstone Formation the base is taken at the change from sandstone and siltstone into bioturbated calcareous siltstone. Eastwards, the Birk Riggs Sandstone Formation thins out and the Coldwell Siltstone Formation rests directly on laminated siltstone of the Brathay Mudstone Formation.

Definition of upper boundary

The upper boundary is an abrupt gradation from bioturbated, calcareous siltstone of the Coldwell Siltstone into laminated mudstone of the Wray Castle Mudstone Formation.

Thickness

In the Lake District the thickness ranges from 47 to 100 m; typically it is up to 10 m in the Howgill Fells, but increases to 30 m locally due to slumping.

Genetic interpretation

The formation is considered to have been deposited under aerobic conditions in an offshore, relatively quiet environment, probably during a fall in relative sea level (Furness et al., 1967; Kneller et al., 1994).

Biostratigraphical characterisation

The lower of the two calcareous units contains a sparse shelly fauna that includes trilobites, brachiopods, a bivalve, a high-spired gastropod, orthocones and crinoid ossicles (Rickards, 1964). Meanwhile, the interleaved hemipelagite unit has yielded *nassa* and *ludensis* biozone graptolites (Rickards, 1969, 1970b; Lawrence et al., 1986). The upper calcareous unit is markedly less fossiliferous than the lower, but within the uppermost 3 m graptolites suggest the *nilssoni* Biozone. A particularly rich *ludensis* Biozone fauna is recorded locally within the Howgill Fells (Rickards and Woodcock, 2005).

Age

Wenlock (Homerian) to early Ludlow (Gorstian).

Geographical limits

From west of Ulverston in the south-west of the Lake District to just east of the A6 road at Shap, and in the Howgill Fells. There is no exposure of these rocks east of this across the Birkbeck Fells to the unconformity at the base of the Old Red Sandstone Group (Soper, 1999).

Maps

Black Combe, Coniston Fells (1:25 000); Ambleside, Kendal, Kirkby Stephen, Kirkby Lonsdale and Ulverston.

8.1.4 Wray Castle Mudstone Formation (WRE)

Name

The formation was first defined by Kneller (1990b) and has subsequently been used throughout the Lake District and Howgill Fells (Kneller et al., 1994; Millward et al., 2000; Johnson et al., 2001; Rickards and Woodcock, 2005) for the Upper Coldwell Beds of Marr (1878, 1892b), Blackie (1933), Furness et al. (1967) and Lawrence et al. (1986). In the south-west of the Lake District the approximate equivalent is the Horrace Flags of Rose and Dunham (1977), or the upper part of the Stennerly Mudstone Formation of Norman (1963).

Stratotype

The type section is on the shore of Windermere lake east of Wray Castle, between 350 m north-west and 200 m south-east of Watbarrow Point [NY 3780 0100] (Kneller, 1990b). A reference section is herein recommended from the Clough River section in the Howgill Fells [SD 6862 9172], which has yielded many graptolites (Rickards and Woodcock, 2005).

Lithology

Laminated muddy siltstone, dark grey when fresh, weathering to paler grey or grey-brown, with subordinate laminae and thin beds of mudstone, siltstone and fine-grained sandstone, commonly graded, and interpreted as the deposits of low-density turbidites. The proportion and thickness of these turbiditic lithologies is less in the lower part of the formation, and decreases westwards. The formation is lithologically similar to the Brathay Mudstone Formation, though with a higher proportion of silt and a greater spacing of lamination. Locally, in the area around Kirkby Moor Quarry [SD 250 838], near the top of the formation, a unit of turbiditic sandstone up to 25 m thick is referred to as the Burlington Member by Kneller et al. (1994) and Johnson et al. (2001).

Definition of lower boundary

The base is taken at the first occurrence of laminated siltstone that overlies intensely bioturbated, nonlaminated calcareous siltstone of the underlying Coldwell Siltstone Formation (Kneller, 1990b). Soper (1999) showed that the Coldwell Siltstone Formation thinned out eastward in the southern Shap Fells and there was no distinction on lithological grounds between the juxtaposed Brathay and Wray Castle mudstone formations. Exposure in the area is too poor for biostratigraphical control on the boundary between them.

Definition of upper boundary

The upper boundary is a transition, typically over about 10 m, into sandstone at the base of the Coniston Group. East from near the head of Crookdale in the southern Shap Fells, where the Gawthwaite Formation at the base of the Coniston Group fails, the Wray Castle Mudstone Formation cannot be distinguished from, and therefore includes, the overlying lateral extension of the Latrigg Siltstone Formation.

Thickness

275 to 550 m in the Lake District; 3–15 m in the Howgill Fells (Rickards and Woodcock, 2005).

Genetic interpretation

The formation represents similar conditions to those prevalent during deposition of the Brathay Mudstone Formation, with deposition in anaerobic conditions from low-density turbidite flows and hemipelagic fall-out.

Biostratigraphical characterisation

The formation has yielded *nilssoni* Biozone graptolites (Rickards, 1967; Rickards and Woodcock, 2005). However, south of Shap where the Wray Castle Mudstone Formation also encompasses strata which are laterally equivalent to the Latrigg Siltstone Formation, the Wray Castle Mudstone Formation may range into the *scanicus* Biozone, though this has not yet been demonstrated.

Age

Gorstian.

Geographical limits

From west of Ulverston in the south-west of the Lake District to Shap, and in the Howgill Fells.

Maps

Black Combe, Coniston Fells, Dalton in Furness (as Horrace Flags) (1:25 000); Ambleside, Kendal, Kirkby Stephen, Kirkby Lonsdale and Ulverston.

8.2 CRAVEN INLIERS

The Brathay Mudstone Formation is described in section **8.1.1**, though it should be noted that the formation here has a more restricted biostratigraphical range than in the rest of the region. Also, the Arcow Formation of McCabe (1972) and Arthurton et al. (1988) is subsumed into the Coldwell Siltstone Formation.

8.2.1 Austwick Sandstone Formation (AUF)

Name

The name was introduced by McCabe (1972) to replace the 'Austwick Flags and Grits' of King and Wilcockson (1934). McCabe's definition was followed by Arthurton et al. (1988). However, in part of the inlier the basal 80 m of their formation comprises carbonaceous siltstones of Brathay facies and this part of the succession was re-assigned to the Brathay Mudstone Formation by Kneller et al. (1994).

Stratotype

Type area is Crummack Dale [SD 770 710 to SD 780 690], about 2 km north of Austwick.

Lithology

Parallel bedded, turbiditic sandstone units, typically in units up to 2 m thick separated by laminated siltstone. The uppermost sandstones are separated from the overlying Arcow Formation by up to 25 m of hemipelagic siltstone, similar to the situation at the top of the Birk Riggs Formation in the Lake District.

Definition of lower boundary

Taken at the base of the first turbiditic sandstones overlying mudstone of the Brathay Mudstone Formation, or northwards, overstepping on to the Stockdale Group and Ashgill strata to overlie greywacke sandstones of the Ingleton Group.

Definition of upper boundary

Defined by the base of the overlying and distinctive siltstone lithology of the Arcow Siltstone Formation.

Thickness

Up to 600 m.

Biostratigraphical characterisation

Based on graptolites, the lower part of the formation is Sheinwoodian, no younger than the *rigidus* Biozone and perhaps as old as the *centrifugus* Biozone (Arthurton et al., 1988), whilst higher parts of the succession contain graptolites indicating a range into the Homerian.

Age

Wenlock (Sheinwoodian to Homerian).

Geographical limits

Restricted to the Craven inliers, North Yorkshire.

Maps

Settle.

Regional correlation

This redefined Austwick Sandstone Formation is considered to be equivalent to the Birk Riggs Sandstone Formation in the Lake District, though sand deposition began earlier.

8.2.2 Horton Siltstone Formation (HNF)

Name

The term Horton Formation was first introduced by McCabe (1972) for part of what previously had been named the Horton Flags (King and Wilcockson, 1934). Arthurton et al. (1988) extended the definition to include the Studfold Sandstone of King and Wilcockson (1934) and the siltstones above. The definition of Arthurton et al. was formalised by Kneller et al. (1994). However, the Studfold Sandstone is typical of the Coniston Group and herein we revert to the original use of Horton Formation for the rocks below the sandstone. Hence, the Studfold Sandstone and the siltstone unit above become formations of the Coniston Group.

Stratotype

The type section, showing the full sequence, is in Tongue Gill, from Billinger Barn to near Sannat Hall Farm [SD8330 6810 to SD 8387 6875], about 1.8 km north-east of Stainforth.

Lithology

Medium to dark grey, laminated, micaceous and partly calcareous sandy siltstones containing carbonaceous debris. Near the base, calcareous nodules occur in layers.

Definition of lower boundary

Taken at the sharp conformable base of a thick sequence of laminated sandy siltstones overlying thickly bedded calcareous siltstones of the Arcow Siltstone Formation.

Definition of upper boundary

Taken at the change from siltstone to turbiditic sandstone of the overlying Neals Ing Sandstone Formation.

Thickness

Up to 710 m.

Biostratigraphical characterisation

The fauna is sparse and generally poorly preserved, but includes graptolites, and from the calcareous nodules brachiopods and orthocones. The *nilssoni–scanicus* biozones of Rickards (1967) are indicated (Arthurton et al., 1988).

Age

Ludlow (Gorstian).

Geographical limits

Restricted to the Craven inliers, North Yorkshire.

Maps

Settle.

Regional correlation

The Horton Formation resembles the Wray Castle Mudstone Formation in stratigraphical position and age, though lithological differences justify separate lithostratigraphical designations.

9 Dalby Group

In the Isle of Man, the Dalby Group comprises a single unit, the Niarbyl Formation.

9.1 WEST COAST

9.1.1 Niarbyl Sandstone Formation (NBY)

Name

The Niarbyl Formation was defined by Morris et al. (1999), replacing the Niarbyl Flags of Lamplugh (1903) and Simpson (1963). The last two authors included these rocks within the Manx Group. Cooper et al. (1995) included volcanic rocks at Ballaquane and Peel within their Niarbyl Formation, which was considered to be Arenig. However, Howe (1999) reported a late Wenlock age for the Niarbyl rocks and Morris et al. (1999) established the Niarbyl Formation within the Dalby Group.

Stratotype

Partial type section in coastal cliff from The Niarbyl to Glen Maye [SC 2107 7758 to SC 2250 7995], Isle of Man (Morris et al., 1999).

Lithology

Thin- to thick-bedded, fine- to medium-grained wacke sandstone with intercalations of silty mudstone, interbedded thinly laminated hemipelagic mudstone and rare beds of metabentonite. The sandstone dominated parts of the succession are interspersed with packages up to 10 m thick of very thin- and thin-bedded, parallel and cross-laminated very fine-grained sandstone, siltstone and mudstone. There are also a few units of massive sandstone in thick to very thick beds.

Boundaries

Neither base nor top of the formation is seen. All contacts with the Manx Group to the east and south-east are faulted.

Thickness

Possibly about 1250 m, but much faulted.

Genetic interpretation

The sandstone successions are interpreted as turbidite sandstone lobe deposits, within which the massive sandstone units probably filled channels. The thin-bedded, parallel and cross-laminated mixed units are thought to represent deposition between lobes or on their fringes. The hemipelagic mudstone represent background suspension sedimentation.

Biostratigraphical characterisation

The formation contains graptolites and orthocone nautiloids, assigned by Howe (1999) to the *lundgreni* Biozone.

Age

Wenlock.

Distribution

Western side of the Isle of Man, between Peel Castle and The Niarbyl.

Map

Isle of Man.

Regional correlation

There are striking lithological similarities with the Brathay and Birk Riggs formations of the same age in the Lake District.

10 Coniston Group

From just west of Ulverston [SD 250 760] in the south-west Lake District to the head of Borrowdale [NY 520 060], the Coniston Group is divided into three sandstone-dominated formations (Gawthwaite, Poolscar, Yewbank), separated by finer grained units (Latrigg, Moorhowe formations) (Figure 10). East of Longsleddale, this 'standard' stratigraphy breaks down because the Gawthwaite and younger Moorhowe formations cannot be recognised. Hence, from Longsleddale eastwards to Shap the group is not divided formally (Millward et al., 2010). In the Howgill Fells the Coniston Group succession is again divided on the basis of the thickness of the component sandstone beds and particularly on the proportion of laminated hemipelagic siltstone that persists in the sequence (Rickards and Woodcock, 2005). There, three hemipelagite-rich units divide the group into four sandstone-rich packets, only the lowest of which, the Screes Gill Formation, is named. These changes in the stratigraphy are recorded on the 1:50 000-scale Geological Survey map for the Kendal district and described in Millward et al. (2010). In general the group is sparsely fossiliferous, though the laminated hemipelagite contains a fauna of graptolites and orthocones. Biostratigraphically the Coniston Group encompasses the *nilssoni–scanicus* Graptolite Biozone of Rickards (1967). In a local refinement (Table 2) this becomes the *nilssoni* to *soperi* Biozones (Rickards and Woodcock, 2005), but Zalasiewicz et al. (2009) reverted to the original.

The Coniston Group and its component formations are interpreted predominantly as the product of turbidity currents deposited in mainly anoxic sea-floor conditions in a flexural foreland basin setting (e.g. Furness et al., 1967; King, 1994). The main sandstone lithofacies were deposited from medium- and high-concentration turbidity flows and represent episodes of turbidite fan growth, whilst the siltstone–mudstone units resulted from low-concentration flows. The laminated siltstone facies represent hemipelagic fallout which built significant intercalated packages between successive episodes of fan growth (Rickards and Woodcock, 2005).

10.1 SOUTHERN LAKE DISTRICT

10.1.1 Gawthwaite Sandstone Formation (GTE)

Name

The term was adopted by Kneller et al. (1994) for the Gawthwaite Sandstone Formation of Norman (1961). It is equivalent to Grit Band 2 of Aveline and Hughes (1872). Lawrence et al. (1986) did not distinguish this unit from their Coniston Grit Formation, but provided detail from the Kendal area.

Stratotype

Type area taken as the hillside north from Green Rigg to the summit of Green Rigg Bank, Torver [SD 2677 9315 to SD 2690 9383].

Lithology

Thin- and medium-bedded sandstone with a fairly high proportion of siltstone and mudstone. Individual, typically normal-graded sandstone beds are rarely more than 50 cm thick and tend to occur as repetitive series of beds cumulatively up to about 15 m thick, alternating with units of laminated siltstone and mudstone up to 2 m thick. Recent descriptions of the formation are given in Millward et al. (2000, p.132) and Johnson et al. (2001, p.52).

Definition of lower boundary

The Gawthwaite Sandstone Formation conformably overlies the Wray Castle Mudstone Formation (Tranearth Group) with its base taken at the incoming of sandstone units.

Definition of upper boundary

Conformably succeeded by the thinly laminated siltstone of the Latrigg Siltstone Formation and is taken where the dominant lithofacies is siltstone.

Thickness

Up to 520 m.

Biostratigraphical characterisation

Though it is only sparsely fossiliferous, graptolites from laminated siltstone suggest that the top of the *nilssoni* Biozone lies in the upper part of the formation (Johnson et al., 2001), though Rose and Dunham (1977) recorded taxa from near the base of the formation that are indicative of a position close to the *ludensis–nilssoni* Biozone boundary.

Age

Ludlow (Gorstian).

Geographical limits

From just west of Ulverston [SD 250 760] in the south-west Lake District to the head of Borrowdale [NY 520 060].

Maps

Black Combe, Coniston Fells (1:25 000); Ambleside, Kendal, Ulverston.

10.1.2 Latrigg Siltstone Formation (LRG)

Name

The Latrigg Siltstone Member was defined by Lawrence et al. (1986) in the Kentmere and Crook area and raised to formation status by Kneller et al. (1994). The term ‘Sheerbate’ has been associated with these rocks because of its reference to their fissility; for example Harkness and Nicholson (1868) described the Sheerbate rocks from the type section. Marr (1892b) adopted the name Sheerbate Flags for this unit and this has been used subsequently by, for example, Furness et al. (1967) and Moseley (1984). However, ‘Sheerbate’ has been used at several stratigraphical levels, and for this reason Lawrence et al. introduced the term Latrigg. In the Ulverston district the formation was referred to as the Stennerly Mudstone by Norman (1961).

Stratotype

The type section is taken in the disused Pennington’s Quarry [NY 4173 0165] about 175 m south of Latrigg Tarn (Lawrence et al., 1986).

Lithology

Thinly laminated hemipelagic siltstone interbedded with subordinate thin beds of fine-grained sandstone up to 50 mm thick. The Latrigg Siltstone Formation is lithologically similar to the Wray Castle Mudstone Formation and, in the southern Shap Fells at the head of Borrowdale where the intervening Gawthwaite Sandstone Formation fails, the Wray Castle Mudstone Formation extends upwards and becomes laterally equivalent to the Latrigg Siltstone Formation

(Millward et al., 2010). Recent descriptions of the formation are given in Millward et al. (2000, p.132) and Johnson et al. (2001, p.52–53).

Definition of lower boundary

The Latrigg Siltstone Formation conformably overlies the Gawthwaite Sandstone Formation, with the base taken at the sharp change from sandstone-dominated to siltstone-dominated sequence.

Definition of upper boundary

The Latrigg Siltstone Formation is conformably overlain by sandstone of the Poolscar Sandstone Formation, with the upper boundary taken at the sharp change to sandstone-dominated lithofacies.

Thickness

0 to 260 m.

Biostratigraphical characterisation

Graptolites from the type locality are indicative of the *nilssoni–scanicus* biozones of Rickards (1967).

Age

Ludlow (Gorstian).

Geographical limits

From just west of Ulverston [SD 250 760] in the south-west Lake District to the head of Borrowdale [NY 520 060].

Maps

Black Combe, Coniston Fells (1:25 000); Ambleside, Kendal, Ulverston.

10.1.3 Poolscar Sandstone Formation (PSR)

Name

The formation name was adopted from Norman's (1961) Poolscar Sandstone Formation by Kneller et al. (1994). The formation corresponds to the lower part of Grit Band 3 of Aveline and Hughes (1872). Lawrence et al. (1986) did not distinguish this unit from their Coniston Grit Formation, but provided detail from the Kendal area. The name is from Pool Scar, about 3 km south-west of Torver.

Stratotype

The type area is on open fell side around Pool Scar [SD 263 914], about 3 km south-west of Torver (Norman, 1961).

Lithology

Thickly to very thickly bedded, medium- to coarse-grained sandstone, commonly amalgamated into sequences several metres thick. Intercalated fine-grained rocks are restricted to the graded tops of the beds. Bioturbation is seen in the fine-grained tops of beds near the base. An exceptionally coarse-grained unit in the central part of the formation contains a derived shelly fauna (Crewdson, 1915). The upper 50 to 60 m of the formation show a progressive decrease in grain size and bed thickness to merge with the overlying Moorhowe Formation. Recent

descriptions of the formation are given in Millward et al. (2000, p. 133) and Johnson et al. (2001, p. 53).

Definition of lower boundary

Taken at the base of the lowest thick-bedded sandstone overlying the siltstone-dominated sequence of the Latrigg Siltstone Formation.

Definition of upper boundary

Gradational lithology change to the overlying Moorhowe Siltstone Formation and taken where siltstone becomes dominant.

Thickness

420 to 700 m.

Biostratigraphical characterisation

No diagnostic fossils have been reported.

Age

Ludlow (Gorstian).

Geographical limits

From just west of Ulverston [SD 250 760] in the south-west Lake District to just east of Longsleddale [NY 505 050].

Maps

Black Combe, Coniston Fells (1:25 000); Ambleside, Kendal, Ulverston.

10.1.4 Moorhowe Siltstone Formation (MHO)

Name

The Moorhowe Member was defined by Lawrence et al. (1986) in the Kentmere and Crook area and raised to formation status by Kneller et al. (1994). This division was recognised and termed the Longsleddale Siltstones by Furness et al. (1967), and corresponds to the Salthouse Mudstone Formation of Norman (1961) and the Rosside Flags of Rose and Dunham (1977).

Stratotype

The type area is the moorland on the northern slopes of Moorhowe between Troutbeck Bridge and Borrans reservoir [NY 411 003 to NY 426 011] (Lawrence et al., 1986).

Lithology

Dark grey, laminated muddy siltstone with subordinate fine-grained sandstone. Recent descriptions of the formation are given in Millward et al. (2000, p. 133) and Johnson et al. (2001, p. 53–54).

Definition of lower boundary

Gradational conformable passage from sandstones of the Poolscar Sandstone Formation and taken where siltstone becomes the dominant lithology.

Definition of upper boundary

Defined at the base of the conformably overlying thick-bedded sandstone sequence of the Yewbank Sandstone Formation.

Thickness

0 to 140 m.

Biostratigraphical

The Ludlow bivalve *Cardiola* from Rosside [SD 271 788] was figured by Rushton and Shepherd (2006).

Age

Ludlow (Gorstian).

Geographical limits

From just west of Ulverston [SD 250 760] in the south-west Lake District to just east of Longsleddale [NY 505 050]. The unit cannot be traced east of Bannisdale in the southern Shap Fells.

Maps

Black Combe, Coniston Fells (1:25 000); Ambleside, Kendal, Ulverston.

10.1.5 Yewbank Sandstone Formation (YBK)

Name

Kneller et al. (1994) adopted the term Yewbank Formation for the upper part of Grit Band 3 of Aveline and Hughes (1872) which corresponds to Norman's (1961) Yewbank Sandstone Formation. Lawrence et al. (1986) did not distinguish this unit from their Coniston Grit Formation, but provided detail from the Kendal area.

Stratotype

The type area is Yew Bank [SD 264 908], about 3 km south-west of Torver (Norman, 1961).

Lithology

Thick to very thick-bedded massive sandstone units, with many thinner and graded sandstone beds and laterally persistent graptolitic siltstone units: the last may attain 20 m in thickness. In the uppermost 170 m or so thin- and medium-bedded graded sandstone units with a sporadically bioturbated siltstone or mudstone capping are common (Millward et al., 2000, p. 133; Johnson et al., 2001, p. 54).

Definition of lower boundary

Conformably overlies the Moorhowe Siltstone Formation and the boundary is taken at the base of the lowest thick-bedded sandstone on thinner bedded siltstone and sandstone.

Definition of upper boundary

The upper boundary is gradational into the conformably overlying Bannisdale Mudstone Formation, with an abrupt decrease in the proportion of sandstone and increase in the number and thickness of banded silty mudstone interbeds. However, towards the south-west and south-east a significant proportion of sandstone units in the base of the Bannisdale Mudstone

Formation makes recognition of this boundary difficult to define (Soper, 1993; Kneller et al., 1994).

Thickness

550 to 1000 m.

Biostratigraphical characterisation

Graptolites from siltstone units indicate the *scanicus* Biozone of Rickards (1967).

Age

Ludlow (Gorstian).

Geographical limits

From just west of Ulverston [SD 250 760] in the south-west Lake District to just east of Longsleddale [NY 505 050]. With the failure of the intervening Moorhowe Formation around the head of Bannisdale, the Yewbank and Poolscar formations cannot be distinguished as separate units farther to the east in the southern Shap Fells.

Maps

Black Combe, Coniston Fells (1:25 000); Ambleside, Kendal, Ulverston.

10.2 HOWGILL FELLS

10.2.1 Screes Gill Sandstone Formation (SGI)

Name

The formation was defined by King (1992) with further details added by Rickards and Woodcock (2005). The formation corresponds with the Lower Coniston Grits of Furness et al. (1967) and Rickards (1967). A possible correlation with the Gawthwaite Sandstone Formation has been proposed (King, 1992; Kneller et al., 1994).

Stratotype

The type section is the continuous, dry stream section and the crags above situated on the north side of Cautley Holme Beck, Howgill Fells [SD 6886 9764 to SD 6848 9773]. This hill slope is misleadingly labelled as Screes on the Ordnance Survey 1:10 000-scale map.

Lithology

Thin, medium, and thick beds of fine-grained sandstone, with each bed grading upwards into a mudstone capping that forms the uppermost one third of the unit. Sequences of these beds are intercalated with units of thin-bedded siltstone–mudstone couplets (Rickards and Woodcock, 2005).

Definition of lower boundary

The base is taken at the base of the first sandstone bed above the laminated siltstone of the Wray Castle Mudstone Formation (Rickards and Woodcock, 2005).

Definition of upper boundary

The top is taken at the change from sandstone to siltstone-dominated sequence at the base of the overlying 30 to 80 m thick, hemipelagite-rich, (informally named) Wotey Gill unit of Rickards and Woodcock (2005).

Thickness

100 to 280 m.

Biostratigraphical characterisation

The hemipelagic facies contains crinoids, orthocones, phyllocarids, the pelagic bivalve *Cardiola interrupta*, as well as graptolites. The fauna is indicative of the *nilssoni–scanicus* Biozone of Rickards (1967), or following Rickards and Woodcock (2005) of the *nilssoni* and *progenitor* Biozones.

Age

Ludlow (Gorstian).

Geographical limits

Howgill Fells and Sedbergh.

Maps

Kendal and Kirkby Lonsdale. It is also present on Kirkby Stephen, though not depicted on the current edition.

Regional correlation

Though the two formations are lithologically and biostratigraphically similar, the Screes Gill Formation is underlain by a very thin (c. 10 m) development of the Wray Castle Formation and hence may be older than the Gawthwaite Sandstone Formation. Thus it is uncertain whether the two formations represent the same, or discrete and possibly overlapping turbidite fans.

10.3 CRAVEN INLIERS

With revision of the Horton Siltstone Formation (Tranearth Group) herein to its original definition by King and Wilcockson (1934), the stratigraphy of units above this proposed by Arthurton et al. (1988) must also be revised. Their Studfold Sandstone (member) becomes the Studfold Sandstone Formation and the dominantly siltstone succession between this and the Neals Ing Sandstone Formation is formally defined herein as the Sannat Hall Siltstone Formation; these three units belong to the Coniston Group.

10.3.1 Studfold Formation (SDS)

Name

These rocks are directly equivalent to the Studfold Sandstone of King and Wilcockson (1934). The strata were subsequently subsumed within an expanded Horton Formation by Arthurton et al. (1988), who recognised for the first time that they were overlain by 250 m of mudstone that intervened between the Studfold Sandstone and another sandstone unit that they designated as the Neals Ing Formation.

Stratotype

Type section in Tongue Gill [SD 8330 6810 to SD 8387 6879], north-east of Stainforth.

Lithology

Poorly sorted, arkosic fine-grained sandstone, mostly thickly bedded; some beds contain calcareous nodules.

Definition of lower boundary

Taken at the sharp base of thick-bedded sandstone above the sequence of laminated sandy siltstones of the Horton Siltstone Formation.

Definition of upper boundary

Defined by the change to dominantly laminated siltstones within the newly defined Sannat Hall Siltstone Formation.

Thickness

40 to 80 m.

Biostratigraphical characterisation

No diagnostic fossils have been reported.

Age

Ludlow (Gorstian).

Geographical limits

Restricted to the Craven inliers, North Yorkshire.

Maps

Settle.

Regional correlation

Kneller et al. (1994) speculated that the Studfold Sandstone Formation might be equivalent to the Gawthwaite Sandstone Formation within the Coniston Group, but this has not been demonstrated.

10.3.2 Sannat Hall Siltstone Formation

Name

This new formation is defined herein for the siltstone succession that overlies the Studfold Formation in the Craven inliers. Its name is from the eponymous farm.

Stratotype

The type section is in Tongue Gill around the farm of Neals Ing, north-east of Stainforth [SD 8410 6905].

Lithology

Medium to dark grey, laminated, micaceous and partly calcareous sandy siltstones containing carbonaceous debris.

Definition of lower boundary

Taken where siltstone beds become dominant above sandstone of the Studfold Sandstone Formation.

Definition of upper boundary

Defined by the base of the overlying sandstone-dominated Neals Ing Formation.

Thickness

Approximately 250 m.

Biostratigraphical characterisation

No diagnostic fossils have been reported.

Age

Ludlow (Gorstian).

Geographical limits

Restricted to the Craven inliers, North Yorkshire.

Maps

Settle (as part of the Horton Formation).

10.3.3 Neals Ing Sandstone Formation (NEI)

Name

The formation was defined by Arthurton et al. (1988) for the sandstone succession that overlies the Horton Formation and comprises the youngest Lower Palaeozoic strata in the Craven inliers.

Stratotype

A partial type section is in Tongue Gill (Silverdale) around the farm of Neals Ing, north-east of Stainforth [SD 8410 6905].

Lithology

Parallel, thick-bedded, turbiditic, arkosic, medium-grained sandstone. Unfossiliferous.

Definition of lower boundary

Taken at the sharp conformable base of sandstone resting on siltstone of the Sannat Hall Siltstone Formation.

Definition of upper boundary

Not seen; unconformably overlain by Carboniferous rocks.

Thickness

At least 250 m.

Biostratigraphical characterisation

No diagnostic fossils have been reported.

Age

Presumed to be Ludlow (Gorstian) by comparison with the potential correlative in the Lake District.

Geographical limits

Restricted to the Craven inliers, North Yorkshire.

Maps

Settle.

Regional correlation

The Neals Ing Sandstone Formation is tentatively correlated with the Poolscar Sandstone Formation of the Lake District (Kneller et al., 1994).

11 Kendal Group

The Kendal Group comprises the Bannisdale Mudstone and Kirkby Moor Sandstone formations (Figure 10).

11.1 SOUTHERN LAKE DISTRICT

11.1.1 Bannisdale Mudstone Formation (BND)

Name

The term Bannisdale Slates was coined by Adam Sedgwick (in Aveline and Hughes, 1872), though Sedgwick (1845, 1846b) had earlier referred to these rocks as the Ireleth Slates. Bannisdale Slates was formalised to Bannisdale Slate Formation by Moseley (1984) and Lawrence et al. (1986). King (1992) and Kneller et al. (1994) removed the lithological epithet.

Stratotype

The type area is Reston Scar [SD 461 983], near Staveley, and a reference section is defined east of Borwick Fold to Land's Lot [SD 446 972 to SD 446 926], south-east of Windermere.

Lithology

Parallel laminated ('banded') siltstone and silty mudstone, with subordinate mudstone and graded beds of sandstone, the last commonly in units up to a few metres thick. Thicker units of turbiditic sandstone occurring at or near the base of the formation have been defined locally as members, despite difficulties in clearly defining the lateral extents of such units. None of these names has been used on published Geological Survey maps and their continued use is not recommended by this report. Mention of these is made here, as follows, for completeness.

In the Furness district, the sandstone unit at the base has been referred to as the Tottlebank Transition Formation (Norman, 1963), the Tottlebank Member (Kneller, 1990b; Kneller and Soper, 1990) and the Rusland Member (Soper, 1993; Kneller et al., 1994). In the Howgill Fells, King (1992) established the Bram Rigg Member at a similar stratigraphical level. The Rusland and Bram Rigg members were adopted by Kneller et al. (1994) and correlated. The Rusland Member was not adopted by Millward et al. (2000), nor by Johnson et al. (2001). Uncertainty in the definition of the Bram Rigg Member led to its use being abandoned by Rickards and Woodcock (2005).

Definition of lower boundary

The basal boundary with the underlying sandstones within the Coniston Group is transitional and the contact is taken where the mudstone and siltstone lithofacies forms the greatest proportion of the sequence. In parts this transition is abrupt, but elsewhere the presence of laterally discontinuous units of sandstone within the basal part of the Bannisdale Mudstone Formation has resulted in the mapped boundary varying in position between different authors in different areas (Lawrence et al., 1986; King, 1992; Soper, 1999; Rickards and Woodcock, 2005).

Definition of upper boundary

Defined by the base of the overlying Kirkby Moor Sandstone Formation and the transition to sandstone-dominated facies.

Thickness

Difficult to estimate because of deformation, but probably in excess of 4000 m in the Coniston to Windermere area, but only about 1400 m in the southern Shap Fells.

Genetic interpretation

The Bannisdale Mudstone Formation rocks were laid down in much the same variety of ways as the Coniston Group, except that low-concentration turbidity flows became the dominant mechanism. Anaerobic bottom-water conditions persisted for much of the time, though increased bioturbation in the upper part of the sequence presaged the change to the more oxygenated environments of the overlying Kirkby Moor Sandstone Formation (Rickards and Woodcock, 2005).

Biostratigraphical characterisation

The Bannisdale Formation has proved very sparsely fossiliferous, though in the Howgill Fells, Rickards and Woodcock (2005) found that the base of the formation lay within their *leintwardinensis* Graptolite Biozone, which is approximately equivalent to the *incipiens* and *leintwardinensis* biozones of Rickards (1967).

Age

Ludlow (Ludfordian).

Geographical distribution

Southern Lake District, from Ulverston north and east to the southern Shap Fells, the Howgill Fells and Kirkby Lonsdale, Cumbria.

Maps

Coniston Fells, Dalton in Furness (1:25 000); Ambleside, Kendal, Kirkby Stephen, Ulverston, Kirkby Lonsdale.

11.1.2 Kirkby Moor Sandstone Formation (KMF)

Name

The term Kirkby Moor Flags was first used by Aveline and Hughes (1872), for the sequence of rocks that had been referred to previously as the 'Upper Slates of Kendal and Kirkby Moor' (Sedgwick, 1845, 1846b). Kirkby Moor Flags has been a constant feature of Lake District classifications, including Marr (1892b), Furness et al. (1967), Ingham et al. (1978) and Moseley (1984; as a member of his Kendal Formation).

In the Kendal area, Shaw (1971) defined a sequence of shelly, fine-grained sandstone beds between the Bannisdale and Kirkby Moor formations as the Underbarrow Flags, replacing the term Passage Beds of Aveline and Hughes (1872). The term has been in use subsequently (Ingham et al., 1978; Moseley, 1984; King, 1992), but Lawrence et al. (1986) were unable to verify Shaw's Bannisdale–Underbarrow boundary and chose a higher level for the base of their Underbarrow Flag Formation. The only lithological boundary that can be widely recognised in this part of the succession in the Kendal area is the passage from Bannisdale 'banded facies' to subtidal sandstone of the Kirkby Moor Sandstone Formation. Because its base cannot be defined lithologically (bioturbation and shelly lags occur sporadically well down into the Bannisdale Mudstone Formation), the Underbarrow Flag Formation was abandoned as a lithostratigraphical unit by Soper (2006).

Largely based on faunas present and the distribution of secondary reddening, Shaw (1971) defined the Scout Hill Flags as a sequence lying stratigraphically above the Kirkby Moor Formation. However, during the resurvey, Soper (2006) could not sustain this on either lithological or structural grounds and the term is abandoned as recommended by Kneller et al. (1994). These rocks are included within the Kirkby Moor Sandstone Formation.

Therefore, by subsuming both the previously separate Underbarrow Flag and Scout Hill Flag formations the definition of Kirkby Moor Sandstone Formation herein differs from that recommended by Kneller et al. (1994).

Formal subdivisions

Includes the Helm Member.

Stratotype

Type section is on Black Crag, north-north-west of Staveley, near Kendal, Cumbria [SD 4647 9933] (Lawrence et al., 1986).

Lithology

The Kirkby Moor Sandstone Formation comprises a sequence of thick beds of massive or convolute laminated, and thin-bedded, ripple-cross laminated fine-grained sandstone. A fine-grained sandstone-dominated lithofacies, transitional from the underlying Bannisdale Formation lithofacies, is present at the base of the formation in the core of the Bannisdale Syncline; the sandstone beds show either parallel bedding or hummocky cross-stratification (Woodcock and Rickards, 2006). Calcareous shelly debris occurs at the base of some of these beds, and some have wave-rippled tops. The sandstone is intercalated with very thin-bedded silt-mud couplets in the lowermost 50 m. Grain size and bed thickness increase upward with medium-bedded units intercalated with thick and very thick beds; though some parallel and hummocky bedforms remain, the major characteristic is large-scale convolute lamination and loaded basal contacts. Stone (2006) described an intercalated reddened siltstone unit within the formation which had been defined as the Helm Member by King (1994).

Definition of lower boundary

The base of the formation is an upwards transition over a thickness of only 2 to 3 m, from the Bannisdale Mudstone Formation into the Kirkby Moor Sandstone Formation. However, in the sequence exposed in the core of the Bannisdale Syncline, pale grey siltstone laminae thicken to over 10 mm, and the rock takes on a distinctive flaggy appearance; this is taken as the base of the Kirkby Moor Sandstone Formation there.

Definition of upper boundary

Not seen as the formation is unconformably overlain by Devonian and Carboniferous rocks.

Thickness

King (1994) illustrated sections up to 746 m thick.

Genetic interpretation

The formation reflects the rapid transition from the anoxic basinal slope environment of the Bannisdale Formation to shallower storm-influenced slopes and to storm-dominated shelf conditions with higher levels of bottom-water oxygenation; reworking by wave action was commonplace (King, 1994). The Helm Member represents deposition by wave action under more sheltered conditions.

Biostratigraphical characterisation

The relatively abundant and diverse shelly faunal assemblages in thin coquinas described by Shaw (1971) includes bivalves, brachiopods, ostracods, bryozoans, gastropods and crinoids. Based essentially on the appearance of critical ostracods taxa, Shaw dated his 'Kirkby Moor Flags' as Whitcliffian, which is now Ludlow (Ludfordian, post-*Bohemograptus* proliferation Biozone of Zalasiewicz et al., 2009) and his 'Scout Hill Flags' as Downtonian, that is now

Pridoli. The Scout Hill Flags now form the upper part of the Kirkby Moor Sandstone Formation (Woodcock and Rickards, 2006). Lawrence et al. (1986) recorded a fauna of early Ludfordian age from the lower part of the formation on Hugill Fell [SD 4565 9912] north-west of Staveley which suggests that the base of the formation is diachronous, younging to the south.

Age

Ludlow (Ludfordian) to Pridoli.

Geographical limits

Southern Lake District and Howgill Fells, Cumbria.

Maps

Kendal; Kirkby Lonsdale.

11.1.2.1 HELM SILTSTONE MEMBER (1HELM)

Name

This was used first by King (1994) and formalised by Kneller et al. (1994).

Stratotype

A partial type section is the disused quarry [SD 5306 8909] on the north-west side of The Helm, a hill to the south-east of Kendal (King, 1994).

Lithology

Laminated siltstone and mudstone with thinly interbedded, fine-grained sandstone that is pervasively reddened (Stone, 2006).

Definition of lower boundary

Taken at the base of the lowest reddened laminated siltstone unit where it overlies thickly bedded, unreddened, coarse- to medium-grained sandstone forming the lower part of the Kirkby Moor Sandstone Formation.

Definition of upper boundary

Taken at the base of the lowest unreddened, thick sandstone bed from the upper part of the Kirkby Moor Sandstone Formation.

Thickness

About 250 m.

Age

Pridoli.

Geographical limits

Restricted to The Helm and its immediate vicinity.

Maps

Kirkby Lonsdale

Appendix 1 Alphabetical list of Ordovician lithostratigraphical units referred to in this report

Obsolete stratigraphical terms are given in Appendix 3.

Name	Map code	Lexicon code	Parent unit	Page
Applethwaite Member		AP	Kirkley Bank Formation	
Ash Gill Mudstone Formation	Ahl	AHL	Dent Group	
Barrule Mudstone Formation	BRUL	BRUL	Manx Group	
Bitter Beck Mudstone Formation	BBF	BBF	Skiddaw Group	
Broughton Moor Limestone Formation	BMr	BMR	Dent Group	
Buttermere Formation	BUF	BUF	Skiddaw Group	
Catterpallot Formation			Skiddaw Group	
Cautley Mudstone Formation	Cmu	CMU	Dent Group	
Crag Hill Limestone Member	CrHl	CRHL	Norber Formation	
Creg Agneash Sandstone Formation	CGA	CGA	Manx Group	
Creggan Moar Mudstone Formation	CRMR	CRMR	Manx Group	
Cystoid Limestone Member	Cyo	CYO	Ashgill Formation	
Dent Group	Dnt	DNT	Windermere Supergroup	
Dufton Mudstone Formation		DNSH	Dent Group	
Drygill Mudstone Formation	DrSh	DRSH	Dent Group	
Glen Dhoo Mudstone Formation	GLDH	GLDH	Manx Group	
Glen Rushen Mudstone Formation	GLRN	GLRN	Manx Group	
Goat Gills Breccia Member	GGM	GGM	Buttermere Formation	
High Pike Haw Member			Kirkley Bank Formation	
Hope Beck Mudstone Formation	Hbe	HBE	Skiddaw Group	
Injebreck Mudstone Formation	IBK	IBK	Manx Group	
Jop Ridding Sandstone Member	JRS	JRSA	Sowerthwaite Formation	
Keisley Limestone Formation		KYL	Dent Group	
Kentmere Limestone Member			Kirkley Bank Formation	
Keristal Sandstone Member	KERI	KERI	Lonan Formation	
Kirkland Mudstone Formation	KdF	KDF	Skiddaw Group	
Kirkley Bank Limestone Formation	KkB	KKB	Dent Group	
Kirk Stile Mudstone Formation	KSt	KST	Skiddaw Group	
Knott Hill Sandstone Formation	KHS	KHSA	Skiddaw Group	
Lady Port Mudstone Formation	LPT	LPT	Manx Group	
Lonan Sandstone Formation	LNN	LNN	Manx Group	
Longsleddale Conglomerate Member	Lsd	LSD	Stile End Formation	
Low Scales Sandstone Member	LwS	LWS	Stile End Formation	
Loweswater Sandstone Formation	LWF	LWF	Skiddaw Group	
Lumholme Conglomerate Member			Broughton Moor Formation	
Manx Group	MANX	MANX	No parent	
Maughold Mudstone Formation	MGD	MGD	Manx Group	
Mull Hill Sandstone Formation	MHL	MHL	Manx Group	
Murton Siltstone Formation	MuF	MUTN	Skiddaw Group	
Norber Formation	NrF	NORB	Dent Group	
Ny Garvain Sandstone Member	NGN	NGN	Lonan Formation	
Rebecca Sandstone Member	Reb	REB	Ashgill Formation	
Robinson Sandstone Member	RMN	RMN	Buttermere Formation	
Santon Sandstone Member		SNTN	Lonan Formation	
Skiddaw Group	SkG	SKG	No parent	
Sowerthwaite Siltstone Formation	SowF	SOW	Dent Group	
Spengill Mudstone Member		SPN	Skelgill Formation	
Stile End Formation	SEn	SEN	Dent Group	
Swindale Limestone Formation	SwL	SWL	Dent Group	
Tailbert Sandstone Formation	Tbt	TBT	Borrowdale Volcanic Group	
Tarn Moor Mudstone Formation	TMF	TMF	Skiddaw Group	
Torver Member			Kirkley Bank Formation	
Troutbeck Siltstone Member			Ashgill Formation	
Wharfe Conglomerate Member		WFC	Sowerthwaite Formation	
Watch Hill Sandstone Formation	WHg	WHG	Skiddaw Group	
Wilsey Beck Sandstone Member		WIL	Cautley Mudstone Formation	
Windermere Supergroup	Win	WIN	No parent	

Appendix 2 Alphabetical list of Silurian lithostratigraphical units referred to in this report

Obsolete stratigraphical terms are given in Appendix 3.

Name	Map code	Lexicon code	Parent unit	Page
Austwick Sandstone Formation	AuF	AUF	Tranearth Group	
Bannisdale Mudstone Formation	Bnd	BND	Kendal Group	
Birk Riggs Sandstone Formation	BkR	BKR	Tranearth Group	
Brathay Sandstone Formation	BrF	BRF	Tranearth Group	
Browgill Mudstone Formation	Brw	BRW	Stockdale Group	
Coldwell Siltstone Formation	Cdw	CDW	Tranearth Group	
Coniston Group	Ctg	CTG	Windermere Supergroup	
Dalby Group	Dby	DALBY	Windermere Supergroup	
Dixon Ground Siltstone Member	DGd	DGD	Brathay Formation	
Far House Siltstone Member	FarH	FARH	Browgill Formation	
Gawthwaite Sandstone Formation	Gte	GTE	Coniston Group	
Hebblethwaite Mudstone Member	Hbw	HBW	Browgill Formation	
Helm Siltstone Member		1HELM	Kirkby Moor Formation	
Horton Siltstone Formation	HnF	HNF	Tranearth Group	
Kendal Group	Kndl	KNDL	Windermere Supergroup	
Kirkby Moor Sandstone Formation	KMF	KMF	Kendal Group	
Latrigg Siltstone Formation	Lrg	LRG	Coniston Group	
Moorhowe Formation	Mho	MHO	Coniston Group	
Neals Ing Sandstone Formation	NeI	NEI	Coniston Group	
Niarbyl Sandstone Formation	Nby	NBY	Dalby Group	
Poolscar Sandstone Formation	Psr	PSR	Coniston Group	
Sannat Hall Siltstone Formation			Coniston Group	
Screes Gill Sandstone Formation	SGi	SGI	Coniston Group	
Skelgill Mudstone Formation	SkB	SKB	Stockdale Group	
Stockdale Group	Stk	STK	Windermere Supergroup	
Studfold sandstone Formation	SdS	SDS	Coniston Group	
Tranearth Group	Tnth	TNTH	Windermere Supergroup	
Windermere Supergroup	Win	WIN	No parent	
Wray Castle Mudstone Formation	Wre	WRE	Tranearth Group	
Yewbank Sandstone Formation	Ybk	YBK	Coniston Group	

Appendix 3 Discontinued and obsolete stratigraphical terms

The use of a small number of unit names should be discontinued following this review. Some of these have been used on maps and in BGS documents, whereas others have been entered in the Lexicon of named rock units, but have not been used. These units are listed below, along with the reasons for discontinuing their use.

Arcow Formation

The Arcow Formation was defined by McCabe (1972) for part of the Horton Flags of King and Wilcockson (1934). Further description was given by Arthurton et al. (1988) and the formation was correlated directly with the Coldwell Siltstone Formation of the Lake District. The recognition of three divisions and the generically similar faunas which include *Cardiola*, *Delops* and orthoconic nautiloids permit the Arcow Formation to be subsumed in a single unit in the whole region. The term Coldwell Siltstone Formation is preferred and use of the term Arcow Formation should be discontinued.

Bram Rigg Member

The Bram Rigg Member was used by King (1992) for a sandstone unit at the base of the Bannisdale Mudstone Formation in the Howgill Fells and was adopted by Kneller et al. (1994) and correlated with the Rusland Member (see below) in the south-west of the Lake District. However, part of the Bram Rigg Member has been included in the Coniston Group by Rickards and Woodcock (2005) who did not use the term Bram Rigg Member. It is recommended herein that use of the term Bram Rigg Member is discontinued.

Burlington Member

A thin sequence of turbiditic sandstone near the top of the Wray Castle Mudstone Formation in the vicinity of Kirkby Moor Quarry in the south-west Lake District was adopted as the Burlington Member by Kneller et al. (1994), citing Soper (1992) as the source; however, the full reference is not given and the other references cited in the paper do not themselves cite the Burlington Member. The member is not depicted on the Ulverston 1:50 000-scale map, nor is it described in the memoir for the district (Johnson et al., 2001). It is recommended herein that use of this term is discontinued.

Capple Bank Member

See Crummack Formation entry below.

Crag Hill Beds

The Lexicon contains an entry of this undefined Ashgill unit within the Norber Formation. It appears to duplicate the Crag Hill Limestone Member of the same formation and is therefore not needed.

Crummack Formation

Introduced in the Craven inliers by Arthurton et al. (1988) to replace Stockdale Shales (now Stockdale Group). The direct equivalent in the Lake District is the Stockdale Group and the term Crummack Formation, and its constituent Hunterstye and Capple Bank members, are considered redundant.

Douk Ghyll Beds

The Lexicon contains this coded but undefined formation of the Dent Group from the Craven inliers. Arthurton et al. (1988) described conglomerate overlain by siltstone at the base of the Norber Formation, exposed in Douk Ghyll, but did not formally use the term Douk Ghyll Beds. The term does not appear on BGS maps and the entry should be regarded as redundant.

Glion Cam Formation

In the Isle of Man, the Glion Cam Unit was included in the stratigraphical scheme of Woodcock et al. (1999) to comprise rocks assigned by Simpson (1963) to the Niarbyl Flags. However, the Glion Cam rocks lie east of the Niarbyl Fault and were re-assigned by Chadwick et al. (2001) to either the Creggan Moar or Glen Dhoo formation. The coded but undefined Lexicon entry for the Glion Cam Formation has not been used on BGS maps and is not needed.

Harlock Formation

The Lexicon contains a partial entry for this unit, formerly the Harlock Grits of Rose and Dunham (1977). These strata are subsumed within the regional Birk Riggs Sandstone Formation and the term Harlock Formation is obsolete.

High Cross Member

Kneller (1990a) divided the Coldwell Siltstone Formation into two formally defined calcareous siltstone members (High Cross and Randy Pike members), separated by an unnamed laminated hemipelagite member. This was adopted by Kneller et al. (1994) and the occurrence in the Ambleside district described by Millward et al. (2000). However, because the definition of the formation carries the main lithologies, these formally defined members are deemed unnecessary and their future use is not recommended.

Horrace Formation

The Lexicon contains a partial entry for this unit, formerly the Horrace Flags of Rose and Dunham (1977). These strata are subsumed within the regional Wray Castle Mudstone Formation and the term Horrace Formation is obsolete.

Hunterstye Member

See Crummack Formation entry above.

Ireleth Member

In Low Furness, the Kentmere Limestone Member of the Kirkley Bank Limestone Formation has been referred to as the Ireleth Member (Kneller et al., 1994; Johnson et al., 2001), after the Ireleth Limestone of Sedgwick (1846b). However, as these are direct correlations in adjacent areas, the term Ireleth Member is here considered unnecessary and designated as obsolete.

Randy Pike Member

See discussion above of the High Cross Member: likewise, it is recommended that use of the term Randy Pike Member is discontinued.

Redmain Formation

The Redmain Formation was established by Allen and Cooper (1986), for the Redmain Sandstone, described originally by Eastwood (1927) and Eastwood et al. (1931) as a correlative of the Latterbarrow Sandstone. However, following the conclusion of Cooper et al. (2004) that the Redmain strata represent highly weathered sandstone belonging to the Loweswater Sandstone Formation, the use of the term Redmain Sandstone is discontinued.

Rusland Member

Norman (1961) recognised the transition between the Coniston Group and the Bannisdale Mudstone Formation in the south-west Lake District in his introduction of the term Tottlebank Transition Formation for the sequence of sandstone in the basal part of the Bannisdale Formation. Kneller and Soper (1990) modified this to Tottlebank Member during part of the resurvey of the Ambleside district, but this was not adopted in the memoir for the Ambleside district (Millward et al., 2000) nor by Kneller et al. (1994). Similar lithofacies in the axial region of the Lowick Anticline were designated the Rusland Member by Soper (1993) and though adopted by Kneller et al. the unit was not depicted on the Ulverston 1:50 000-scale map, nor described in the memoir (Johnson et al., 2001). As explained by Johnson et al., the upper boundary and lateral extent are difficult to define clearly, and for this reason it is recommended that use of the term Rusland Member should be discontinued.

Scout Hill Formation

Previously the Scout Hill Flags of Shaw (1971). See discussion under Kirkby Moor Sandstone Formation. These rocks are subsumed within the Kirkby Moor Sandstone Formation (Section 11.1.2) and use of the term should be discontinued.

Swindale Shale Formation

Hirnantian strata exposed in Swindale Beck in the Cross Fell Inlier have been traditionally assigned to the Swindale Shales (Burgess and Holliday, 1979; Arthurton and Wadge, 1981). In their review Kneller et al. (1994) re-assigned these rocks to the Ashgill (now Ash Gill Mudstone) Formation in recognition of their similar lithofacies and faunal assemblages. This practice has been followed on the BGS 1:50 000-scale Sheet 30 (Appleby) (Millward et al., 2003). It is therefore recommended that use of the terms Swindale Shales and Swindale Shale Formation are discontinued.

Underbarrow Flag Formation

Previously the Underbarrow Flags. See discussion under Kirkby Moor Sandstone Formation (Section 11.1.2). These rocks are subsumed within the Kirkby Moor Sandstone Formation and use of the term should be discontinued.

Upper Skelgill Beds

The Lexicon contains this undefined entry which should now be regarded as obsolete. Marr and Nicholson (1888) divided their Skelgill Beds into lower, middle and upper units, but these have not been used in recent accounts and there is no current need for these as formal divisions.

Appendix 4 Borrowdale Volcanic Group

TAILBERT SANDSTONE FORMATION

Name

The formation was defined by Bell (1997) and named after Tailbert Farm, near Shap, Cumbria. Though Bell did not assign the unit to a parent group, Millward et al. (2003) included the Tailbert Formation in the Skiddaw Group, while Cooper et al. (2004) considered this tentative.

Stratotype

The type area is Tailbert Bank, 500 m west and north-west of Tailbert Farm, Shap [NY 5245 1400 to NY 5300 1465].

Lithology

Dominantly thick, massive beds of well sorted, medium-grained volcaniclastic sandstone up to 1 m thick, separated by thin volcaniclastic siltstone units up to several centimetres thick and locally with ripple cross-lamination (Bell, 1997). Over much of the outcrop, the siltstone is missing, giving the appearance of a uniform featureless sandstone. Locally, there are intraclasts of mudstone, volcaniclastic siltstone and tuff, typically a few centimetres across. Towards the top of the formation there are some interbedded thin, dark grey mudstone units, similar to those seen in the underlying Skiddaw Group.

Definition of lower boundary

The contact is nowhere seen, locally the formation is inferred to lie unconformably above steeply dipping mudstone of the Tarn Moor Mudstone Formation (Skiddaw Group).

Definition of upper boundary

Overlain unconformably by rocks at the base of the Borrowdale Volcanic Group.

Thickness

At least 200 m.

Age

The age has not been constrained biostratigraphically though it is presumed to be Llanvirn or early Caradoc.

Geographical limits

Restricted to the Bampton Inlier, west of Shap, Cumbria.

Maps

Appleby.

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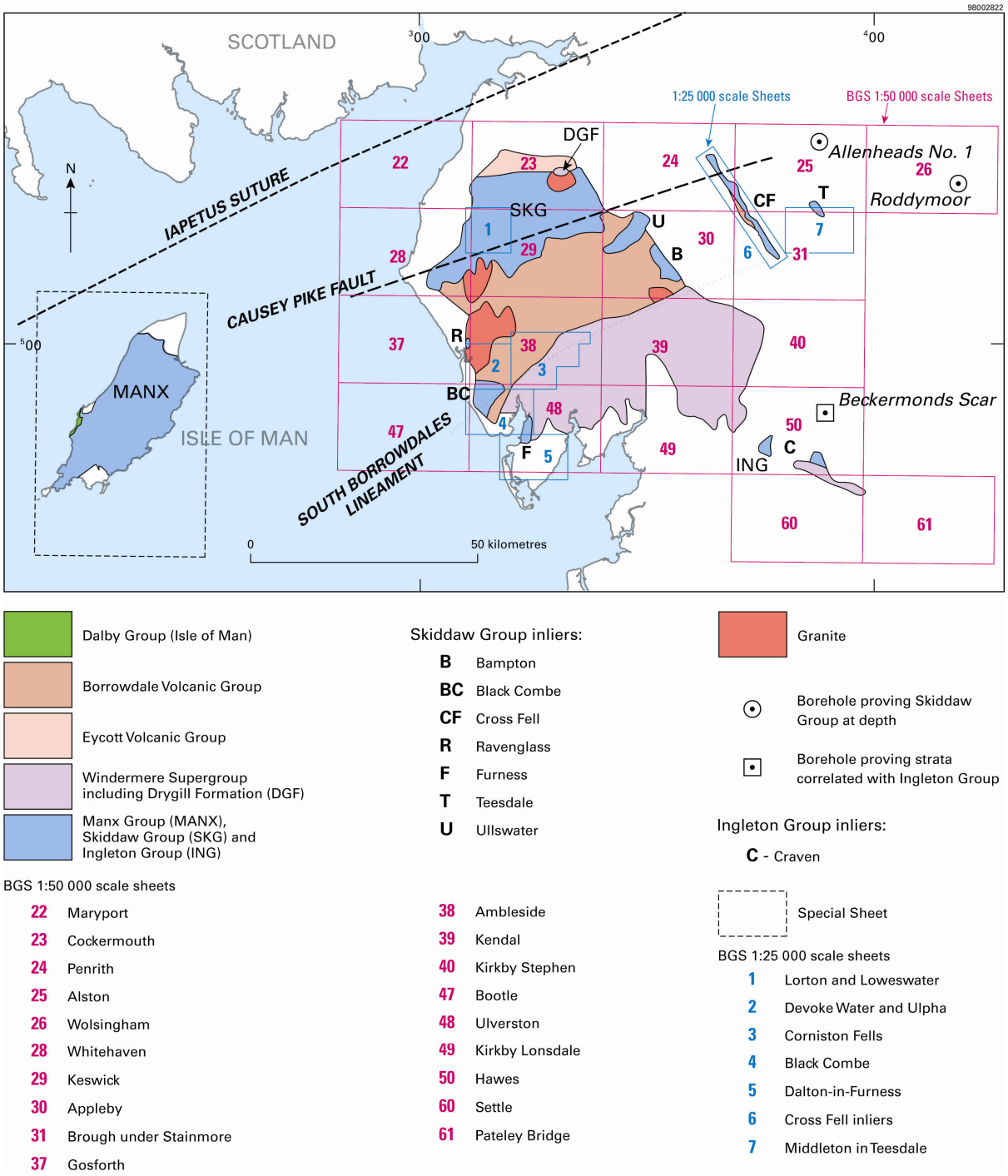


Figure 1 Distribution of the major lithostratigraphical divisions of the Ordovician and Silurian strata in northern England and the Isle of Man. Also shown are the localities of boreholes proving Skiddaw Group strata at depth. The approximate positions of the BGS 1:50 000 and 1:25 000-scale geological maps are shown.

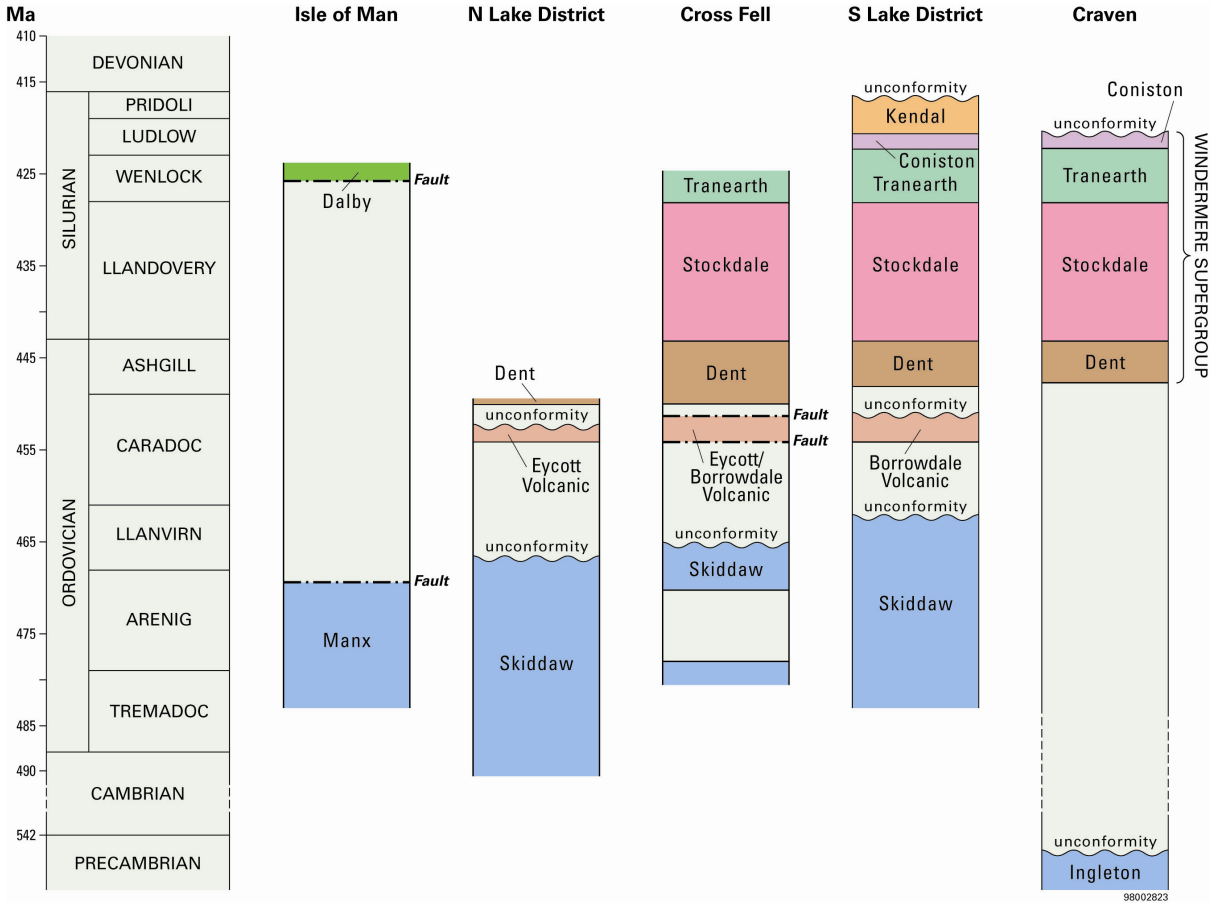


Figure 2 Stratigraphical framework for Ordovician and Silurian strata of the Lake District, Isle of Man and adjacent areas of northern England. All units are groups. Absolute ages from the International Stratigraphic Chart.

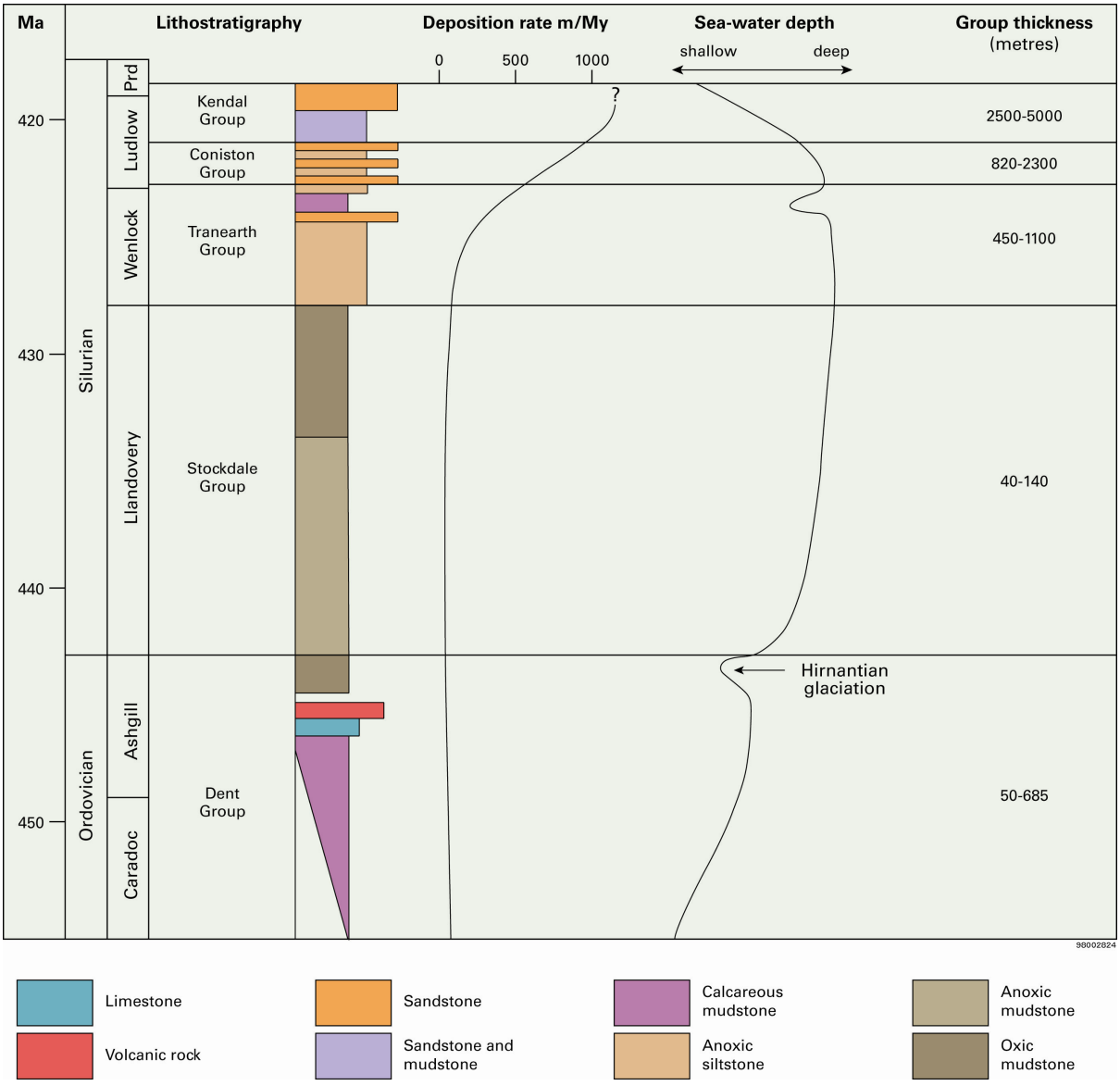


Figure 3 Variation in lithofacies, sedimentation rate and sea-water depth during deposition of the Windermere Supergroup (after Rickards and Woodcock, 2005). Prd Pridoli. Sea-water depth curve is much simplified.

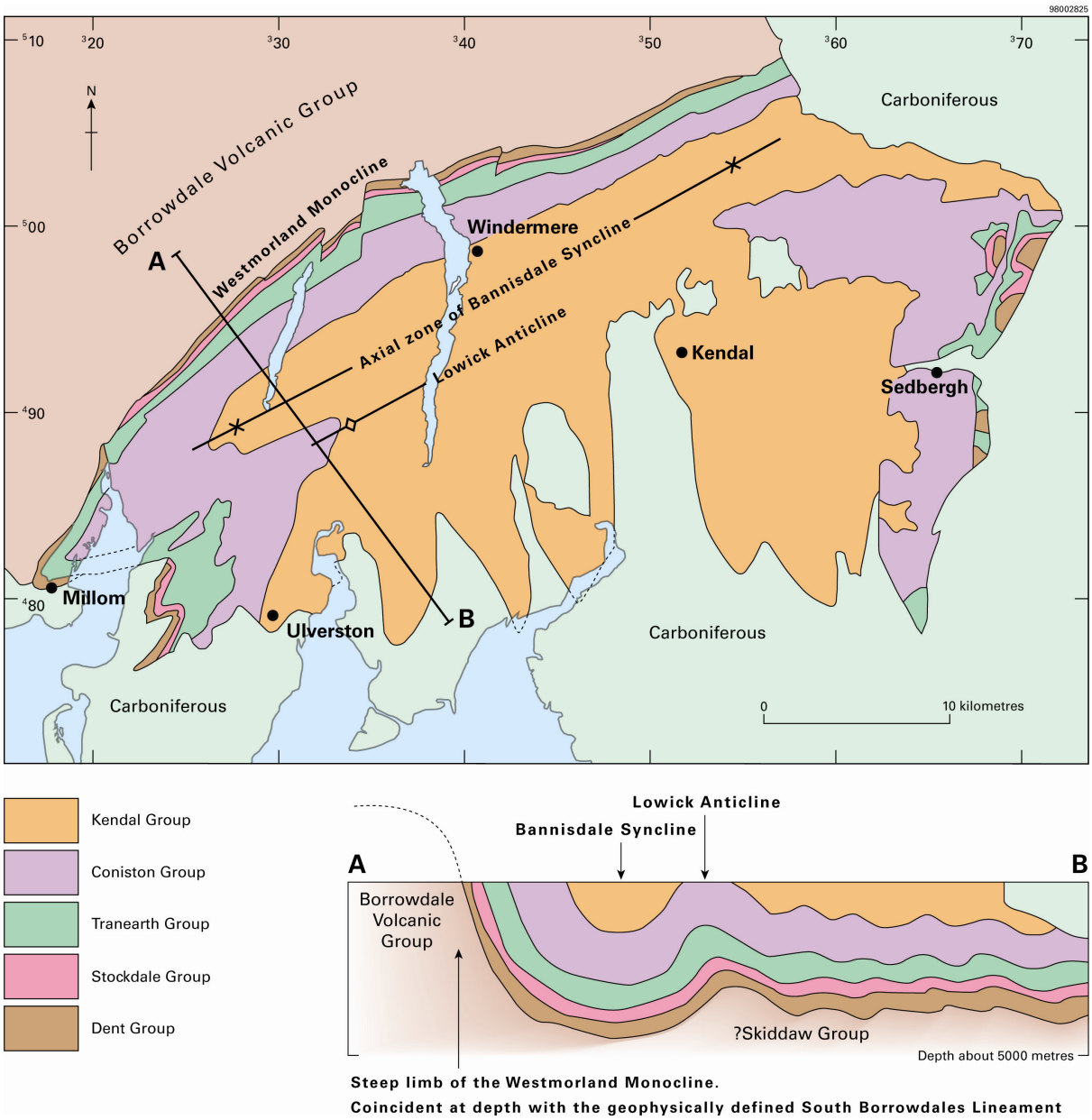


Figure 4 Generalised geological map showing the distribution of the groups within the Windermere Supergroup in the southern Lake District.

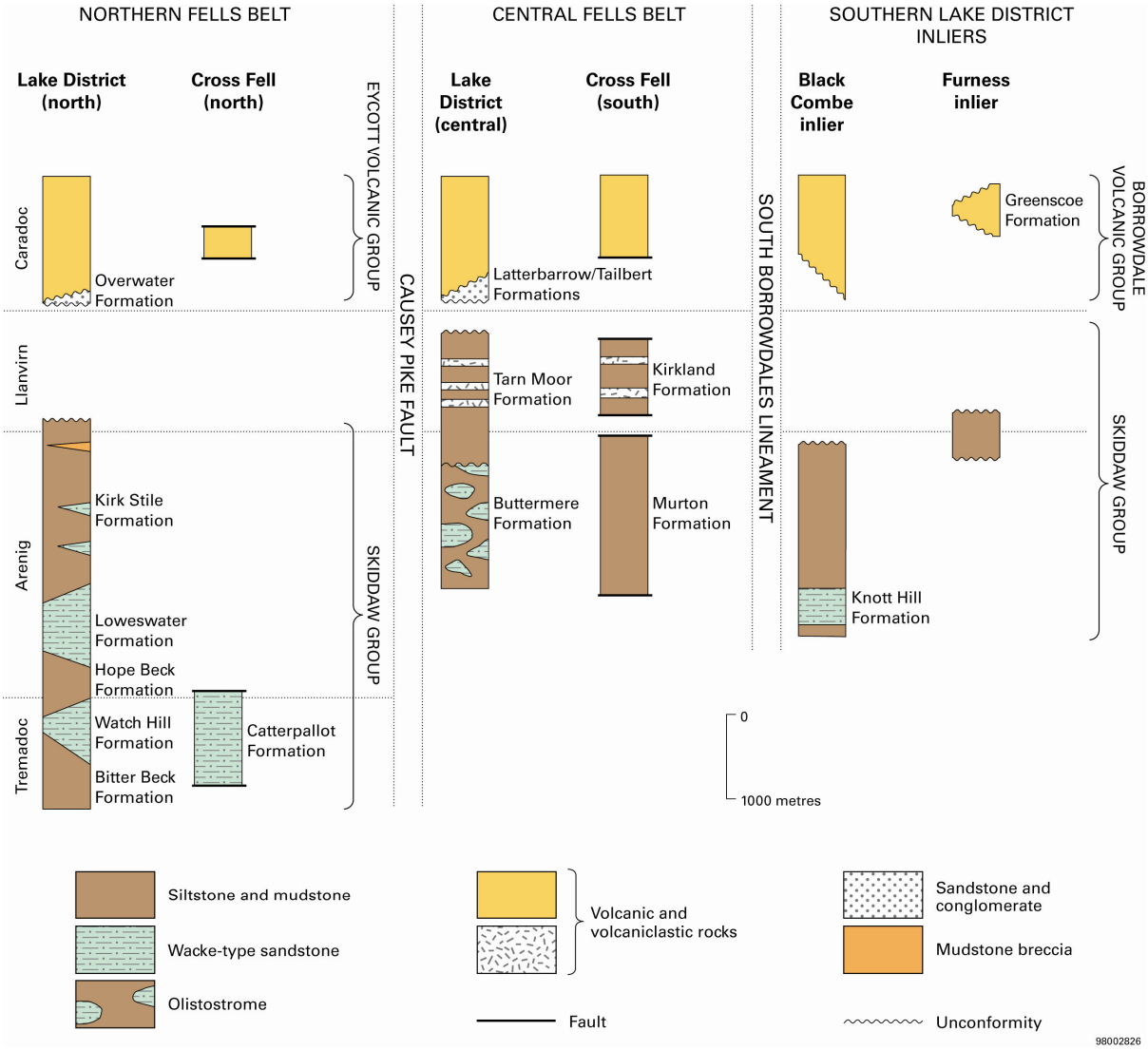


Figure 5 Stratigraphical correlation of the Skiddaw Group between the Lake District and Cross Fell inliers (after Cooper et al., 1995).

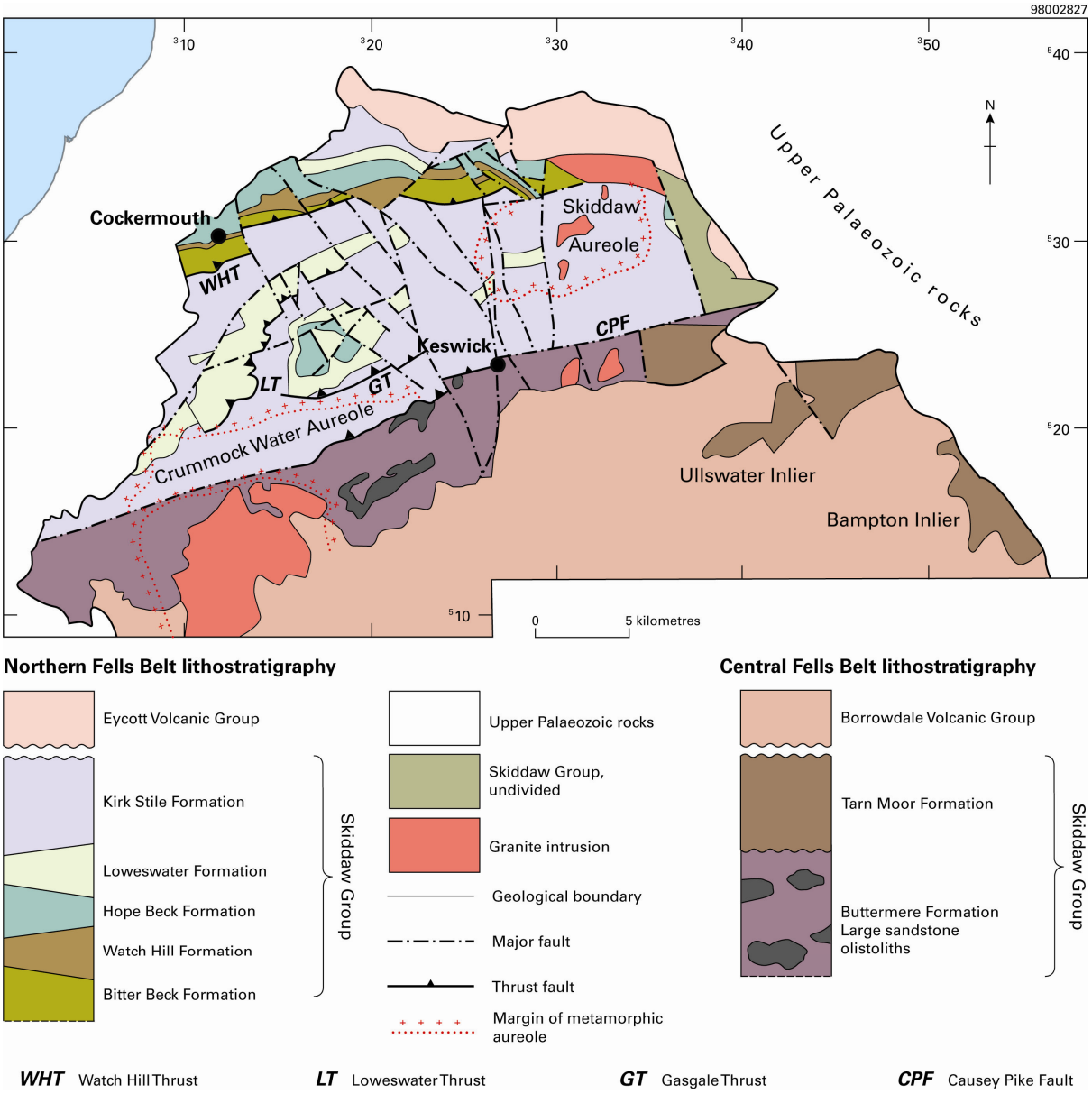


Figure 6 Outline geological map of the Skiddaw Group inliers in the northern Lake District.

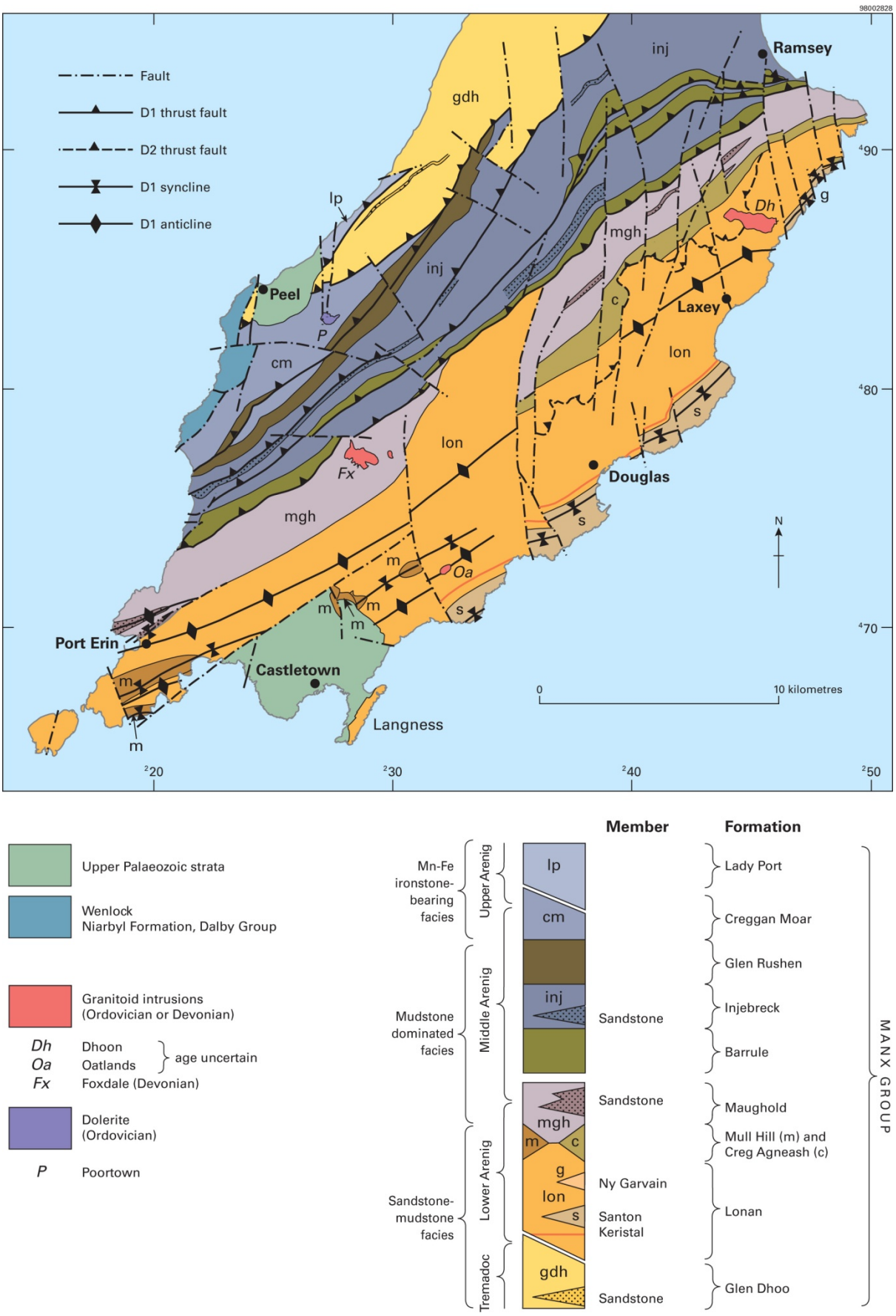
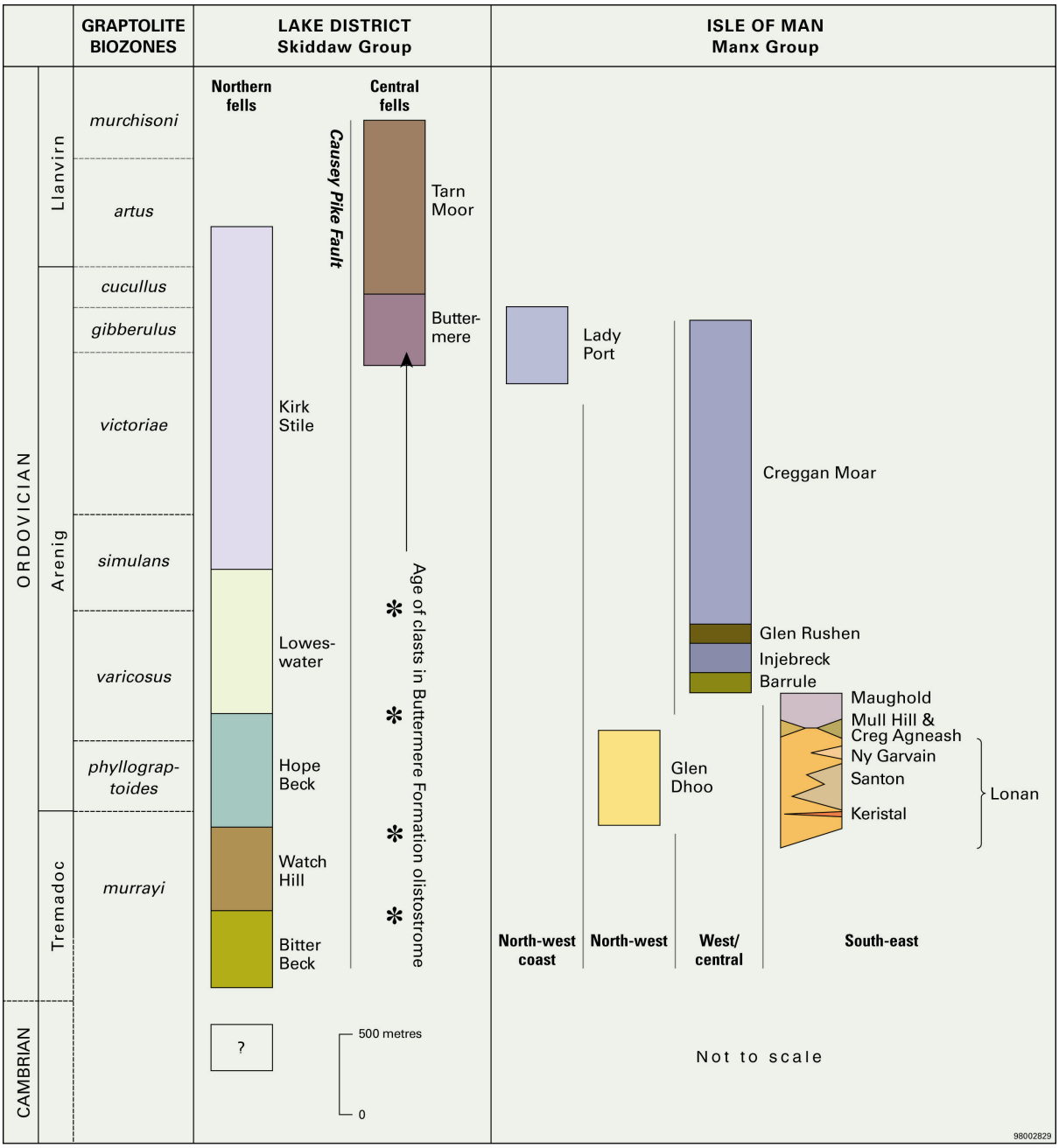


Figure 7 Outline geological map of the Manx and Dalby groups in the Isle of Man.



All named units are formations, except for Ny Garvain, Santon and Keristal which are members of the Lonan Formation

Figure 8 Stratigraphical correlation between the Skiddaw and Manx groups.

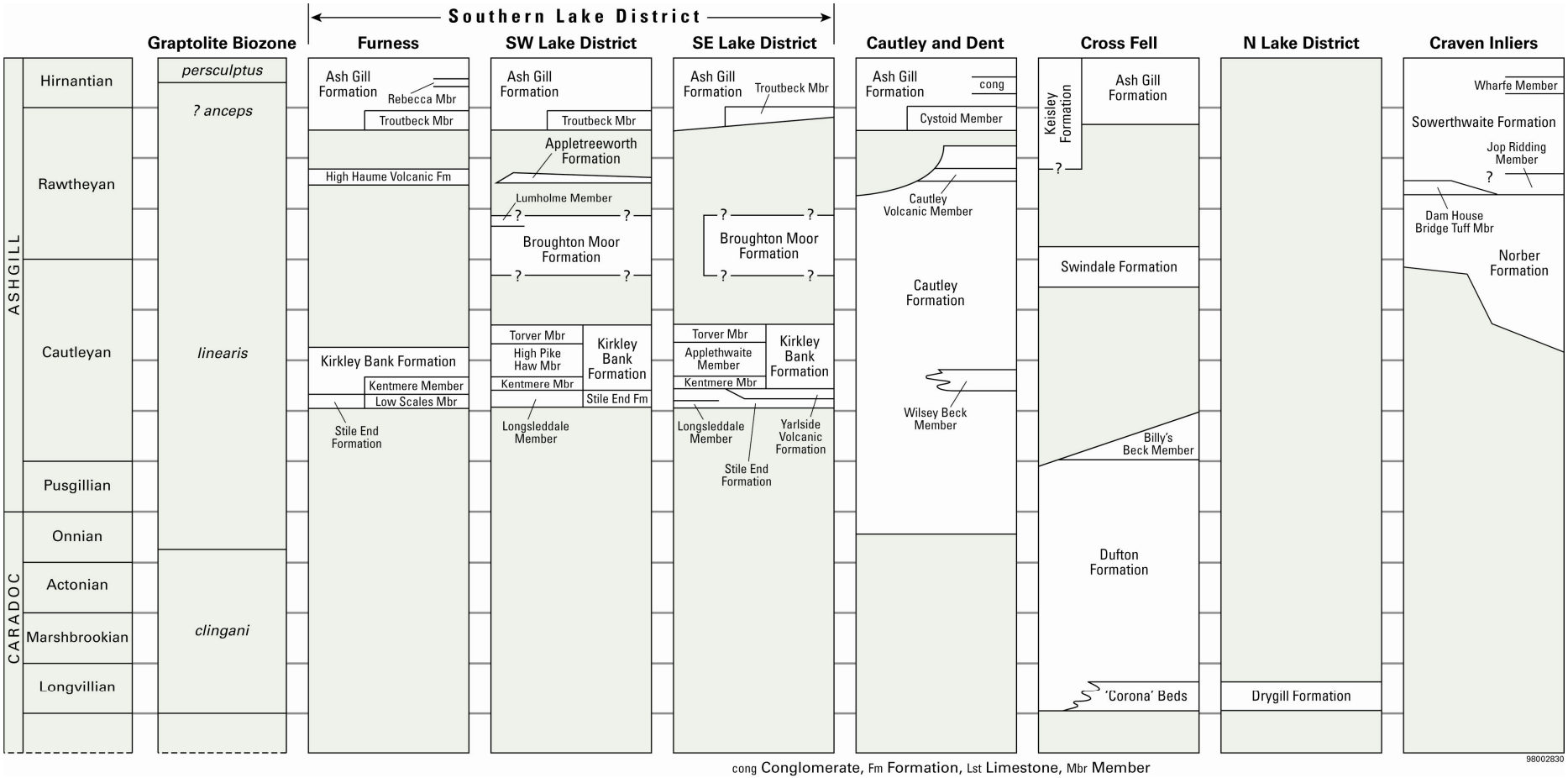


Figure 9 Regional correlation of the Ordovician strata of the Dent Group (modified from Kneller et al., 1994). Lithological epithets are omitted from the named units for clarity – see text for full formal names.

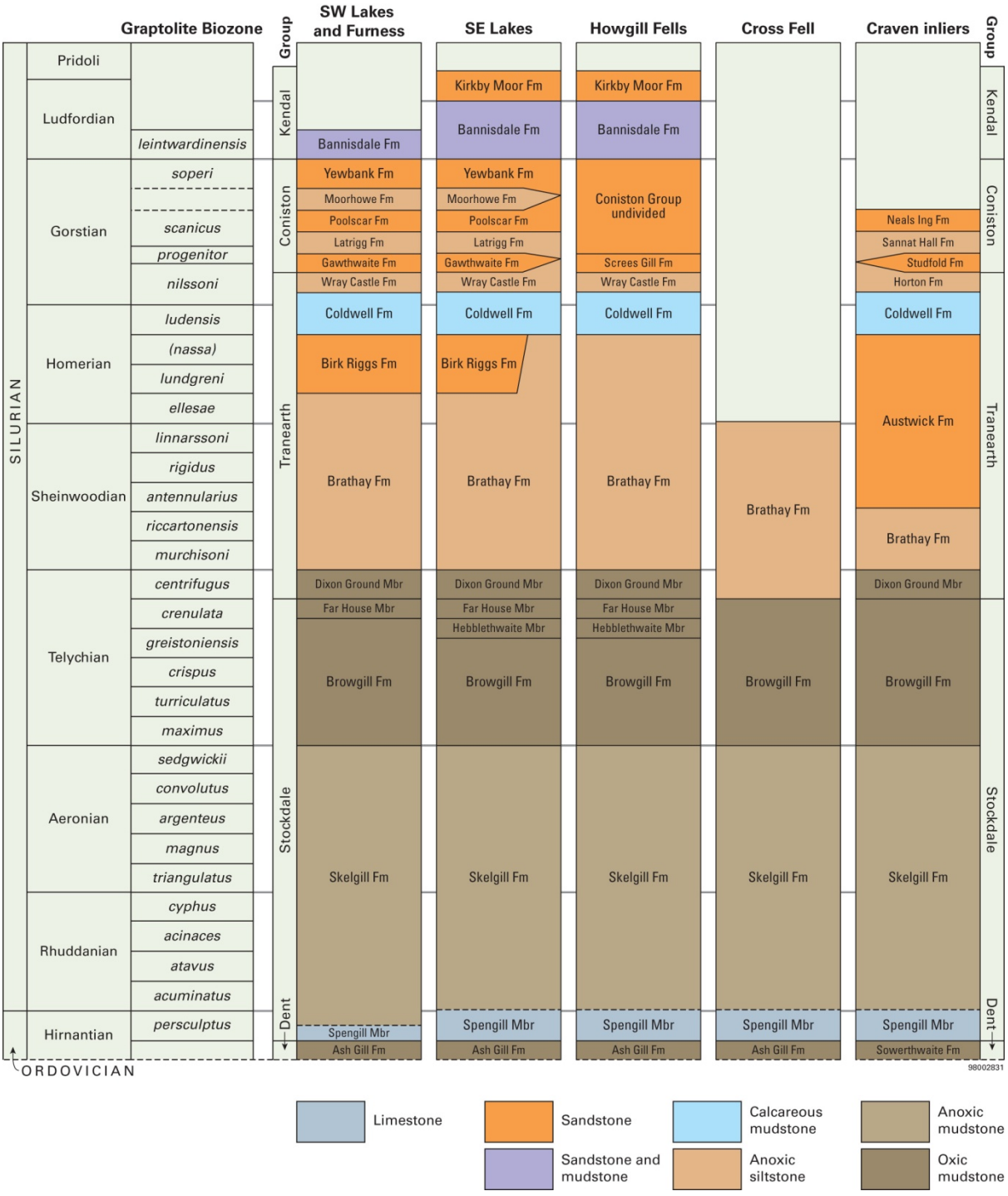
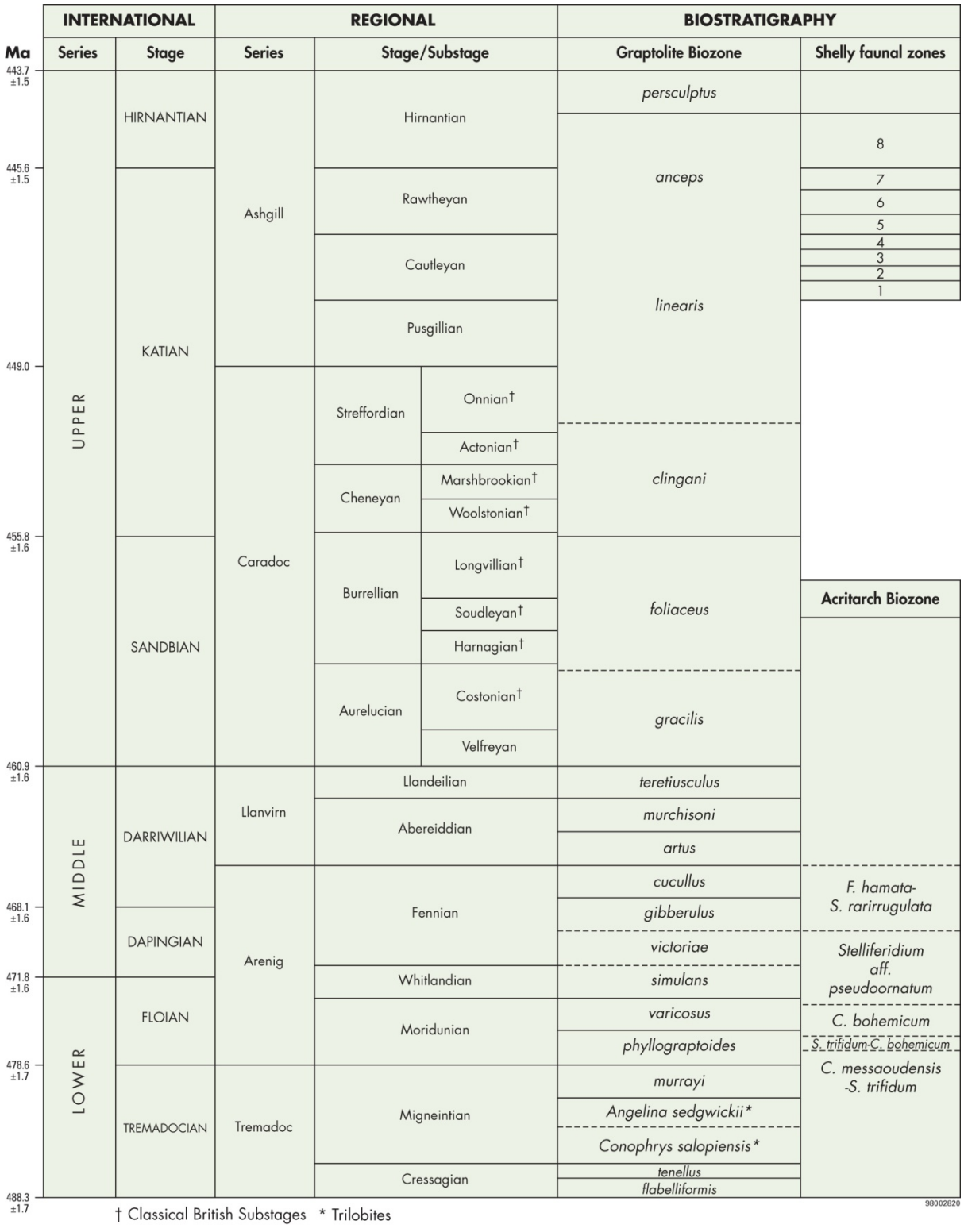


Figure 10 Regional correlation of the Silurian strata within the Windermere Supergroup. The Helm Siltstone Member is omitted from the Kirkby Moor Sandstone Formation for clarity. Lithological epithets are omitted from the named units for clarity – see text for full formal names.

Table 1 Chronostratigraphical subdivision and current graptolite biozonation for the Ordovician System as applied in the Lake District and adjacent areas. International divisions and radiometric ages are from the International Stratigraphic Chart for 2009; British Regional Stages from Fortey et al. (1995, 2000); biostratigraphy from Cooper et al. (2004), Ingham (1966), Rickards and Woodcock (2005) and Zalasiewicz et al. (2009).



† Classical British Substages * Trilobites

Table 2 Chronostratigraphical subdivision and current graptolite biozonation for the Silurian System as applied in northern England. International divisions and radiometric ages are from the International Stratigraphic Chart for 2009. Graptolite biozones used in Northern England are from Rickards (1989) with emendations by Rickards and Woodcock (2005). British graptolite biozones are from Zalasiewicz et al. (2009). Note that Zalasiewicz et al. (2009) place the base of the Wenlock Series at the base of the *murchisoni* Graptolite Biozone whereas, previously this boundary has been taken at the base of the *centrifugus* Biozone.

Ma	Series	Stage	Graptolite Biozone	
			Northern England	Zalasiewicz *et al.*, 2009
416.0	PRIDOLI			No biozone in British Isles
418.7	LUDLOW	Ludfordian		*Bohemograptus* proliferation biozone
			leintwardinensis	*Saetograptus leintwardinensis*
421.3		Gorstian	*soperi*	*Saetograptus incipiens*
			scanicus	*Lobograptus scanicus*
			progenitor	*Neodiversograptus nilssoni*
			nilssoni	
422.9	WENLOCK	Homerian	*ludensis*	*Monograptus ludensis*
			nassa	*Gothograptus nassa*
			lundgreni	*Cyrtograptus lundgreni*
			ellesae	
426.2		Sheinwoodian	*linnarssoni*	*Cyrtograptus rigidus*
			rigidus	*Pristiograptus dubius*
			antennularius	*Monograptus riccartonensis*
			riccartonensis	*Monograptus firmus*
			murchisoni	*Cyrtograptus murchisoni*
428.2	LLANDOVERY	Telychian	*centrifugus*	*Cyrtograptus centrifugus*
			crenulata	*Cyrtograptus insectus*
				Cyrtograptus lapworthi
				Oktavites spiralis
				Monoclimacis crenulata
			griestoniensis	*Monoclimacis griestoniensis*
			crispus	*Streptograptus sartorius*
				'Monograptus' crispus
			turriculatus s.l.	*Spirograptus turriculatus*
			maximus	*Spirograptus guerichi*
436.0		Aeronian	*sedgwickii*	*Stimulograptus halli*
				Stimulograptus sedgwickii
			convolutus	*Lituigraptus convolutus*
			argenteus	*Pribylograptus leptotheca*
			magnus	*Neodiplograptus magnus*
			triangulatus	*Monograptus triangulatus*
439.0		Rhuddanian	*cyphus*	*Monograptus revolutus*
			acinaces	*Huttagraptus acinaces*
			atavus	*Atavograptus atavus*
443.7			*acuminatus*	*A. ascenus - P. acuminatus*

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